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EC-18B/BOEING 707 SMOKE VENTING FLIGHT TEST

Captain Daniel J. Mokris
4950 TESTW/DOBB

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This ~~technical~~ report presents the results of the Smoke Venting flight test on a USAF C-18, a modified B-707 aircraft. A 3" by 4" Smoke Elimination Valve (SEV) was installed in a metal window plug in a fuselage window forward of the wing's leading edge. The SEV consisted of a hinged flat plate that extended out into the slipstream. The local airflow accelerated around the plate, decreasing pressure in the area, creating a draw that pulled smoke from the cabin of the aircraft. The objective of the test was to prove feasibility of the SEV for venting smoke. The aircraft was instrumented with smoke density detecting light meters and a computerized data collection system. First, a baseline test of the aircraft's pressurization and air conditioning system was conducted. Then the SEV was opened to assess its smoke clearing capabilities. Smoke clearing time constants were developed to gauge the system's performance and ranged from 57 to 555 seconds, depending on the test condition. While the SEV did exhaust smoke, complex airflow patterns within the cabin appeared to cause air stagnation in certain areas. This in turn forced the time

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19. (cont) constants to increase when the SEV was opened, a trend exactly opposite of what was expected. Recommendations were made to reaccomplish the tests using a more realistic scenario, repeat runs to increase reliability of data collected, and use some means to visualize local flow patterns in certain key areas around the cabin. The test was conducted by the 4950 Test Wing, WPAFB, OH in Jul 1988.

Keywords: Jet transport aircraft pressurization; Smoke venting flight testing; Aircraft fires, Smoke clearing.

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This report has been reviewed and is approved for publication.

JAMES H. DOOLITTLE III, Colonel, USAF
Deputy Commander for Operations, 4950th Test Wing

ROBERT F. RAGGIO, Colonel, USAF
Commander, 4950th Test Wing

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SUMMARY

A baseline flight test program was performed on an EC-18B aircraft, USAF S/N 81-0896, to obtain data on the effectiveness of a Smoke Elimination Valve (SEV). The valve was designed to draw smoke from the cabin and exhaust it into the external airflow.

The aircraft was modified by installing the SEV in place of a cabin window and then instrumenting the valve and cabin to measure pressures and free-air light transmissivity.

The test objectives centered on isolating the effects of the SEV from those of the aircraft pressurization and airconditioning system to determine the SEV's ability to vent smoke. One sortie of 3.2 hours duration was flown out of Wright-Patterson AFB, Ohio on 22 July 1988.

While the SEV clearly drew smoke from the interior of the aircraft and vented it overboard, the complexity of the cabin airflow patterns complicated a precise determination of the SEV's effectiveness.

FOREWORD

This was a development, test and evaluation program to assess the utility of a SEV installed flush to the aircraft skin. When the valve was extended into the airstream, smoke was drawn from the interior of the aircraft and vented overboard. Funding for this program came from the FAA Technical Center in Atlantic City, New Jersey which was the Participating Test Organization. The 4950th Test Wing was the Responsible Test Organization. The program Job Order Cost Accounting System number was W05604SE.

ACKNOWLEDGMENTS

This project matured through the efforts of an entire team of technicians, engineers, and flight test personnel. Of that team the following people provided major contributions: Mr Tobin Denney, 4950 TESTW/FF, was the project engineer devising and developing instrumentation as well as drafting and reviewing portions of the text. Major Carl Berdahl, 4952 TESTS/DOBT, proposed the use of least squares curve fitting techniques for data reduction and wrote that portion of the text. Both Mr Denney and Major Berdahl acted as sounding boards for the test program manager, providing insight, expertise, and logic to many ideas and problems encountered.

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ABBREVIATIONS

AFB	- Air Force Base
ALT	- Altitude
AMX	- 4950th Test Wing Directorate of Aircraft Modification, Special Projects Division
APP	- Approach
CDCS	- Computerized Data Collection System
FAA	- Federal Aviation Administration
FE	- Flight Crew Engineer
FFDA	- 4950th Test Wing Directorate of Flight Test Engineering, Aircraft Dynamics Branch
fpm	- feet per minute
FS	- Fuselage Station
HQ AFSC/IG	- Headquarters AF Systems Command Inspector General
JOCAS	- Job Order Cost Accounting System
K	- Thousands of feet altitude MSL
KIAS	- Knots Indicated Airspeed
MSL	- Mean Sea Level
mv	- Millivolts
PA	- Powered Approach
Pd1/2	- Differential Pressure Gauges 1 and 2
PRS	- Pressure
SEV	- Smoke Elimination Valve
S/N	- Serial Number
TC	- Turbocompressor
TW	- Test Wing
USAF	- United States Air Force
VMC	- Visual Meteorological Conditions

SECTION I

INTRODUCTION

1.1 BACKGROUND

Problems with smoke and toxic fumes in aircraft cockpits and cargo compartments have contributed to several accidents in both military and civilian aircraft. In 1985, the USAF Military Airlift Command conducted ground and in-flight smoke and fume elimination tests following the crash of a C-141B aircraft at Sigonella, Italy, (see Reference 1). Test results revealed that the current technical order smoke and fume elimination procedures were inadequate. These results focused attention on the problem of effectively venting toxic and vision-restricting smoke and fumes from aircraft cabins. Subsequently, HQ AFSC/IG tasked the 4950th Test Wing to investigate the problem.

In addition to standard technical order procedures for venting smoke from aircraft cabins, the FAA was interested in developing alternate procedures, including aircraft modification, to improve the ability of aircrews to quickly vent smoke. The Smoke Venting program's goal was to demonstrate the feasibility of a SEV for quickly venting cabin smoke. The SEV was designed and manufactured for the FAA by Adams Rite Products Inc. of Glendale, California. The valve, when opened, extends into the slipstream, locally accelerating the flow and thereby dropping the local static pressure. This reduced static pressure draws air from the cabin (assuming the cabin has inflow with pressure higher than the SEV's pressure). The FAA will test the valve in a Boeing 727 with the goal of placing operational versions on aircraft worldwide. Since the C-18 aircraft is essentially a commercial Boeing 707-300, the FAA requested that the 4950th Test Wing flight test the SEV on a C-18. To minimize aircraft modification and demodification, the valve was designed to fit into any fuselage side window or overwing escape hatch window.

1.2 TEST OBJECTIVE

The purpose of this flight test was to determine the effectiveness of the SEV for clearing smoke from the cabin. Normal C-18/Boeing 707 Cabin Smoke Removal procedures entail maximizing the inflow rate and driving the outflow valves full-open, thereby increasing the rate and volume of airflow through the cabin. For this test it was assumed that in an operational scenario, the SEV would be used along with normal aircraft smoke and fume elimination procedures. Accordingly, this test only investigated aircraft pressurization system modes of operation where some type of inflow was present.

SECTION II

TEST ITEM AND MODIFICATION DESCRIPTION

2.1 TEST ITEM

The Adams Rite SEV is basically a 3" x 4" plate that extends outward from the skin of the aircraft(see Figures 2-1 through 2-3). The airflow around the plate, through the Venturi effect, drops the static pressure at the valve's throat. This reduced pressure draws air from the aircraft interior and vents it overboard. The valve has a maximum opening angle of 43 degrees and was not certified airworthy by the manufacturer. 4950 TESTW/AMX certified the valve airworthy to 10,000 feet and up to 250 KIAS, in unpressurized flight.

The SEV has ten settings. Settings 0 and 9, fully closed and fully open respectively, feature mechanical overcenter locks. Moving the SEV from position 1 to 0 or 8 to 9 only engages the overcenter lock and does not actually move the position of the flat plate. Of the possible positions, 2, 4, 7 and 9 were selected to sample differential pressure data. The SEV was designed to be installed in a metal window plug of a C-18 window.

2.2 MODIFICATION DESCRIPTION

2.2.1 Window Plugs. SEV/window plug installation on the aircraft involved fitting the SEV/window plug configuration into a fuselage window or an overwing hatch window space. A second metal window plug, on the right side of the fuselage directly across from the SEV, was modified by drilling a 1/16 inch hole. Its function was to sample the local static pressure. Locating the SEV and pressure tap in a window position minimized aircraft downtime and ensured a standardized installation. Modification and demodification time was limited to that required to change out the window plugs. Since all the windows on the C-18 take the same size plug, the modified plug and valve could be placed in any cabin window position on the aircraft.

2.2.2 SEV Location. For the flight test, the SEV and metal plug were installed at fuselage station (FS) 600G + 10 (see Figures 2-4 and 3-2). This location was selected for two reasons.

The first is the boundary layer. Originally, the SEV was to be located in an overwing hatch, but analysis by 4950 TESTW/FFDA revealed that at that point the boundary layer was 6 to 7 inches deep. Since the SEV only extends approximately 4 inches into the boundary layer, the test team located the SEV at FS 600G + 10 where the boundary layer is only 4 to 5 inches thick.

The second reason is the pressure distribution. Locating the SEV over the wing put it in a natural low pressure area due

to the lift generated by the wing. Consequently, the wing's pressure field would affect the SEV's performance by dropping the outside pressure below normal freestream static pressure. The SEV's final mounting location (FS 600G + 10) was thought to be far enough away from the wing's influence to affect near freestream static pressure. Panel Code Analysis by 4950 TESTW/AMDA revealed that the pressure coefficient at FS 600G + 10 was 0.02 or roughly 2% of the maximum computed value found anywhere on the aircraft. For our purpose, this meant that the tendency for airflow to enter or exit the aircraft through a simple opening at this position was negligible. Thus, at this point on the fuselage, assuming airspeed and altitude remain constant, the main mechanism for dropping the pressure is the SEV's local acceleration of the airflow.

2.3 AIRCRAFT PRESSURIZATION

The aircraft pressurization system's sources of inflow consist of bleed valves on all four engines, Turbocompressors (TC) on the inboard engines (see Figure 6-1), and ram air inlets in the air conditioning system. The airflow is channeled to the cabin by a distribution and supply ductwork. Once in the cabin, it exits through the cabin air return cavity between the fuselage and cabin walls and is normally dumped overboard through one of two outflow valves along the keel of the aircraft located forward and aft.

SECTION III

INSTRUMENTATION AND TEST EQUIPMENT

3.1 INSTRUMENTATION

3.1.1 Pressure Gauges. Two differential pressure gauges were installed in the vicinity of the SEV. Pressure leads for the first differential pressure gauge (Pd1, see Figure 3-1) came from the throat of the SEV and from the pressure tap in the window plug on the opposite window position. This pressure tap in the window plug mirrored the position of the SEV. The difference between the two pressures indicated the pressure drop created by the SEV assuming the aircraft was not in sideslip.

The pressure leads for the second differential pressure gauge (Pd2, see Figure 3-1) came from the throat of the SEV and from a reference opening sampling ambient cabin air a foot from the gauge. This pressure differential measured the pressure buildup in the cabin above that in the flow separation bubble created by the SEV.

3.1.2 Computerized Data Collection System (CDCS). The FAA-provided CDCS consisted of three major components: light sensors, an Acrolog 900 data acquisition system and a Zenith 183 laptop computer. The eight light sensors were 18 inch self-contained emitter/receptor units weighing 2.5 pounds each, developed by the FAA Technical Center, Atlantic City, NJ. These units were spaced evenly throughout the cabin (see Figure 3-2). The sensors were placed in sets of two, one knee height (18 inches) and the other at shoulder height, (60 inches) along the right side of the cabin. The light sensors were spaced approximately 230 inches apart.

Each light sensor measured a representative sample of the smoke density in its area. Prior to smoke generation, the light sensors transmitted a maximum millivolt reading which represented clear air. As smoke was generated and the path between the sensor's emitter and receptor became clouded, less light from the emitter would reach the receptor, and the millivolt reading would decrease. The sensors were designed with a directional light baffle to decrease the skewing of results due to varying levels of ambient light. The baffle was a 30 inch hollow tube, 3/4 of an inch in diameter, and painted black inside and out.

Each light sensor was calibrated individually, and tested to ensure proper response. Each sensor was operated while exposed to a 50% and 100% light filter to ensure that the data transmitted to the Acrolog 900 corresponded. Therefore, if the smoke clouded the air so that only 50% of the clear air light transmission level was achieved, the millivolt readings for a given sensor would be 1/2 the original maximum value for that sensor. By dividing the real-time millivolt reading by the

maximum, an indication of transmissivity could be obtained. A light transmissivity of approximately 10% indicates a situation in which an object can be seen at a distance of no more than one meter.

The sensors fed their data in millivolts to the Acrolog 900 data acquisition system. The Acrolog averaged the values, formatted the data and sent it to the Zenith 183 computer for data storage. This equipment was mounted on a Wheaton table located on the left-hand side of the aircraft at FS 730.

3.2 TEST EQUIPMENT

3.2.1 Smoke Generation Equipment. The FAA-provided smoke generator vaporized a latex based smoke agent with an electrically energized heating element. The smoke agent produced non-toxic smoke and did not leave any type of residue or film deposit on the the interior of the aircraft. The use of this agent and its smoke generator, resulted in no irritations or complaints from crew members during this test.

3.2.2 Photographic Equipment. For documentation purposes, still photos of the SEV and the modification were taken. During the flight, VHS video footage of smoke behavior was recorded in the cabin from start to end of run.

SECTION IV

TEST PROCEDURES

4.1 GROUND TEST

In the interest of safety and aircrew familiarization, a full ground rehearsal of the test sequence was completed prior to flight. The following ground test guidelines were observed:

a. All flight test members were required to participate in the ground test.

b. An external air cart was connected to the aircraft to provide inflow, although it was at a lower rate than that experienced during flight.

c. After the cabin filled with smoke, the flight crew practiced flight manual Cabin Smoke Removal procedures for familiarization.

d. All personnel practiced and became familiar with the use of interphone and oxygen systems, as well as the demands of their specific job when the cabin was filled with smoke. One run of each of the four sets of flight conditions from Figure 4-1 was simulated.

4.2 FLIGHT TEST GENERAL

The test consisted of a single day-VMC flight of 3.2 hours duration flown from Wright-Patterson AFB, Ohio in restricted area R-5503A. Aircraft gross weights for takeoff and landing were approximately 200,000 and 164,000 pounds respectively. Since an open SEV would depressurize the aircraft, the entire flight was flown depressurized at or below 10,000 feet MSL altitude. Zero sideslip, constant airspeed flight was maintained during data collection. During the one powered approach (PA) configuration run, the airspeed was not less than the appropriate 40 degree flap approach speed. To comply with the depressurized flight requirement, the aircraft pressurization outflow valves were driven open manually after engine start and remained open until after landing, with one exception. During run 1 all inflow was shutoff and then the outflow valves were driven closed. Engine bleed valves were not opened during this flight. The FAA requested SEV data during climb, cruise and descent phases of flight. For this reason data were collected in the 13 different runs shown in Figure 4-1.

4.3 TEST CONDITIONS

During the flight, four principle sets of flight conditions were investigated as indicated in Figure 4-1 and Table 4-1. The first was: (1) the amount of differential pressure generated by

the SEV in different opening positions (runs 2-4). The purpose of these runs was to determine the optimum opening position of the SEV. This setting was then used for runs 8-13. Runs 5-13 included climb, cruise and descent phases of flight.

The last three sets of flight conditions dealt with various inflow/outflow/SEV configurations and they were: (2) smoke removal with TC inflow and the SEV closed for a baseline reference (runs 5-7); (3) smoke removal with TC inflow and the SEV open (runs 8-10); and (4) smoke removal with ram air as the source of inflow and the SEV open (runs 11-13). Except for run 1, the outflow valves were driven full open for the entire flight.

4.4 FLIGHT TEST SEQUENCE

4.4.1 Runs 1-4. The sequence for the flight test was as follows: Ten minutes after takeoff, level at 5,000 feet MSL in the restricted area R-5503, run 1 was performed and pressure data collected. Next, while still level at 5,000 feet MSL, runs 2, 3, and 4 were conducted at 250KIAS, 200KIAS, and approach airspeed respectively. During each run, the SEV was placed in positions 2, 4, 7, and 9 and pressure data were collected to determine the optimum SEV position.

4.4.2 Runs 5-7. These were baseline climb, cruise, and descent runs respectively at 250KIAS. The SEV remained closed and smoke was generated during each run. The runs were planned to last five minutes and CDCS light data were collected continuously. Pressure data were also recorded.

4.4.3 Runs 8-10. These were climb, cruise, and descent runs respectively at 250KIAS. These runs differed from 5-7 in that in addition to the baseline aircraft pressurization inflow/outflow, the SEV was opened to the optimum position determined in runs 2-4. Smoke was generated and CDCS and pressure data were collected in the same manner as runs 5-7.

4.4.4 Runs 11-13. These were climb, cruise, and descent runs respectively at 250KIAS. In these runs, ram air became the source of inflow while the SEV was set to the optimum position determined in runs 2-4. Smoke was generated and CDCS and pressure data were collected in the same manner as runs 5-7. Following run 13 the aircraft returned to Wright-Patterson AFB.

4.5 DIFFERENTIAL PRESSURE RECORDING

The pressure differentials were read in inches of water and recorded manually after the pressure had stabilized during all runs. During run 1, the differential pressure was read with the SEV in positions 0 and 9, all inflow off. For runs 2-4, the differential pressure was read with the SEV in positions 2, 4, 7 and 9. For runs 8-13, the pressure was read with the valve in position 7.

4.6 SEV POSITION OPTIMIZATION

During runs 2-4 the pressure differential gauges were used to determine which SEV setting was optimum. The pressure differential between the valve throat and external air (see Figure 3-1) was recorded and the position resulting in the largest differential was identified as the optimum valve position.

4.7 Pd READINGS

Pressure differential readings were taken during runs 5-13 in an effort to quantify the effect of cabin pressurization on SEV operation. The pressures were read directly off the pressure differential guages and were presented in Table 6-2.

4.8 VIDEO DATA

VHS video data of each smoke run (runs 5-13) were recorded from the time smoke generation was stopped until the run ended.

4.9 CDCS DATA

Light sensor data collection began when smoke started filling the cabin and continued as the SEV was opened. Data collection stopped when further smoke removal became negligible. With this technique, data collection generally lasted about eight minutes for a given run (three minutes to fill the cabin with smoke and five minutes to conduct the run).

4.10 SAFETY CHASE

Due to the potential of smoke in the cockpit restricting the pilots' ability to see their instruments, a T-39 safety chase aircraft was required. The chase remained with the test aircraft for the first three smokings and then was released after it was decided the smoke did not present a visibility problem in the cockpit.

SECTION V

DATA REDUCTION AND ANALYSIS

5.1 SEV POSITION OPTIMIZATION

Runs 2-4 generated the data presented in Table 6-1. The data were analyzed during the flight to determine the optimum SEV opening position. SEV position #7 created the maximum Pd for all combinations with the exception of a minor variation from the general trend in RUN/SEV POS# 3/9. Position #7 or 34.4 degrees open, was then used as the SEV open position for runs 8-13.

5.2 CDCS DATA

The CDCS provided an output in millivolts and data analysis involved normalizing it by dividing all millivolt outputs by the maximum (clear air) millivolt output for each sensor to obtain a measure of transmissivity and to negate the effect of the various sensors having varying maximum output values. Plots of the normalized light sensor data are presented in Figures A-1 through A-14.

5.3 DATA PROBLEM IDENTIFIED

After reviewing Figures A-1 through A-14, it was decided that, while the graphs did indicate smoke dissipation during the runs, they did not conveniently compare the relative merits of the different inflow/outflow/SEV combinations described in Figure 4-1, e.g. the rate of smoke decay. Consequently, least squares curve fitting was employed to derive more useful information from the data.

5.4 MODELING OF SMOKE CLEARING

The following describes the mathematical analog used to model the physics of the smoke clearing. For our purpose, it can be assumed that the cabin of an aircraft is initially a closed system and that it contains a finite number of air and smoke particles. In this test, the only means of inflow were either TC or ram air operation, and the only paths for outflow, discounting leaks, were the aircraft's outflow valves and the SEV. In steady state conditions, for every ten particles of air that enter the aircraft, ten particles also exit, taking with them an undetermined number of smoke particles. For each successive ten particles of the mixture that exit, the probability of exhausting smoke particles decreases as the cabin smoke density falls. This decay-type behavior can easily be modeled by an exponential curve. One unique property of this exponential curve is that a time constant or Tau can be computed and used to compare rates of smoke decay regardless of the beginning and ending smoke density levels.

5.5 TAU DEVELOPMENT

An explanation of least squares curve fitting of an exponential curve to this data is described below.

It's convenient to transform the normalized transmissivity data before fitting it. Initially, a given data run appears like that in Figure 5-1. Notice how the transmissivity data (a variable called T1) begins at about 0.8 at the smoke off point and decays with time towards 1.0 (perfectly clear air). By subtracting T1 from 1 and calling the result T2, T2 is forced to decay from 0.2 towards 0. Finally, by taking the natural logartithm of T2, T2 is transformed into a variable, T3, that traces a straight line with time, Figure 5-2.

Now, the equation for a straight line can be fit to the transformed smoke data (the T3 space) using standard least squares curve fitting techniques. It is assumed in the beginning that the data in the T3 space fits to a straight line (Equation 1).

$$T3 = C1 + C2t \tag{1}$$

Here, C1 and C2 are constants, and (t) denotes times. Curve fitting of Equation 1 to a given data set involves tracking the difference between the measured values of T3 and the values of T3 predicted by Equation 1. For each data point, the error is squared to force it to be non-negative. Then, the individual squared errors are summed to arrive at an overall error of Equation 1's deviation from the sampled data. Finally, values of C1 and C2 are chosen to minimize this overall error. This requires taking the partial derivatives of C1 and C2 with respect to the overall error, setting these two partial derivatives equal to zero, and solving the resulting system of simultaneous equations. This technique is futher discussed in Reference 2. Application of this least squares curve fitting in the T3 space generated fits as shown in Figure 5-2. Note the curve fitted line drawn through the sampled data.

Next Equation 1 is transformed back to our original or real world space to show how a time constant that describes decay of the smoke was extracted. Exponentiation of Equation 1 yields Equation 2.

$$T2 = e^{T3} = e^{(C1 + C2t)} \tag{2}$$

Using a commonly known property of exponential functions, we obtain Equation 3.

$$T2 = e^{C1} e^{C2t} \tag{3}$$

Further transformation by subtracting T2 from 1 (Equation 4) returns the data back to the original space, T1.

$$T1 = 1 - e^{C1} e^{C2t} \qquad (4)$$

At this point a time constant Tau is defined and set equal to -1/C2. Substituting into Equation 4 yields Equation 5.

$$T1 = 1 - e^{C1} e^{-t/Tau} \qquad (5)$$

Tau describes the amount of time it takes the system to decay to 37 percent of its starting value. It can be shown that this holds true by noting that the exponential of zero (for time zero) is 1, while the exponential of -1 (for time Tau) is 0.37. Thus, a very useful means of quantitatively assessing the smoke clearing effectiveness of the different inflow/outflow/SEV configurations has been found. It is simply the time constant, Tau, for the decay of the smoke density (note that Tau does not depend on the starting or ending densities of the smoke but only on the rate at which the smoke clears).

A table of the smoke clearing time constants, Tau, for the different inflow/outflow/SEV conditions appears in Table 6-3. Plots of curve fitted exponential functions to the sampled data appear in Figures B-1 through B-14.

SECTION VI

TEST RESULTS AND DISCUSSION

6.1 PRESSURE DIFFERENTIAL DATA

6.1.1 Runs 2-4. The pressure differential data indicate that for this aircraft, with the SEV installed at the specified location, the optimum SEV open position was #7. This valve position generated the largest pressure differential. During the remainder of the testing, whenever the test plan called for the SEV to be open, the valve was opened to position #7. The data obtained during Runs 2-4 are presented in Table 6-1.

6.1.2 Runs 5-13. During the smoking runs (5-13), pressure data were collected and are presented in Table 6-2. Runs 5-7 were a baseline test of the aircraft pressurization system, so the SEV remained closed for these runs. Runs 8-13 involved opening the SEV and noting the change in pressure. The runs in general show an initial pressure reading as the smoke generation is initiated, another when the valve is opened to position 7, and a final reading at end run after the valve is closed. As expected, pressure variation was negligible once stable. Engine power setting changes may have caused some of the Pd2 variation due to corresponding TC inflow changes. The average pressure drop at the SEV during these runs was 10 to 11 inches of water.

6.1.3 Pd1 Anomaly. When first recorded during the flight test the Pd1s, in Tables 6-1 and 6-2, were positive. After further analysis of the physics of separation bubbles and the aircraft's pressurization system, it was concluded that the pressure sensing system was incorrectly plumbed. The pressure leads to the back of the Pd1 pressure gauge had been inadvertently connected incorrectly. The pressures should have been negative and the signs in the figures were changed to a negative to correct this mistake.

6.2 LIGHT SENSOR DATA

6.2.1 Runs 5-13. Light sensor data were collected during runs 5-13, with the exception of runs 7 and 12. Data from these two runs were inadvertently not recorded on disk and subsequently lost during the flight test. The data for sensors 0, 1, 2 and 3 appear to be consistent and the most reliable collected. (These sensors were located in the forward cabin and were closest to the smoke source.) Sensors 4, 5, 6 and 7 were located in the aft cabin and were not subjected to high enough levels of smoke to provide sufficient valid data for a good assessment of the SEV's impact on smoke removal in the aft end of the aircraft. In addition, sensor 6 repeatedly provided a randomly fluctuating output signal and its reliability was judged doubtful. Therefore, the majority of conclusions are based on data from sensors located in the forward end of the cabin, in close

proximity to the smoke source and the SEV.

6.2.2 Runs 7 and 12. These represent a descent condition with the SEV closed and a cruise condition with the SEV open, respectively. The loss of these two data points makes it difficult to compare the effect of the valve during cruise and descent phases of flight, although all data points are available for climbing flight. The light sensor data for run 5 are presented in Figure 5-1.

6.3 SMOKE CLEARING TIME CONSTANTS

6.3.1 Figures B-1 through B-14. As discussed in paragraph 5.3, the raw data plots of light transmissivity (Figures A-1 to A-14) presented limited usefulness. Therefore the least squares curve fitting and time constant computation techniques were employed to extract more useful information from the data. Figures B-1 through B-14 show these curves and the time constants computed for sensors two and three during runs 5, 6, 8, 9, 10, 11 and 13. Each graph shows the normalized transmissivity data as small boxes and the exponential function curve fitted to this data. The sampled data agree very well with the exponential function for some runs (eg. run 5), suggesting that the exponential function does, in fact, accurately model the behavior of smoke clearing. Some runs show poorer agreement, perhaps because the smoke may have moved in clouds that convect past the sensor in clumps.

6.3.2 TAU Table. Table 6-3 shows all the computed time constants for sensors two and three during runs 5, 6, 8, 9, 10, 11 and 13. The climb, cruise and descent phases of flight are listed across the top and inflow/SEV conditions are listed vertically on the left. Data lost on runs 7 and 12 hampers analysis, however, some trends can be found.

6.3.3 TAU Trends. The climb is the only phase of flight for which a complete comparison of configurations, (TC inflow/SEV closed, run 5 vs TC inflow/SEV open, run 8 vs Ram inflow/SEV open, run 11) can be made. In run 5, the time constants are around 110 seconds. When the SEV is opened in run 8, theoretically clearing the smoke more quickly, the time constant increases to around 275 seconds. Then in run 11 when ram air provides the inflow with the SEV open, the average time constant increases further to an average of 420 seconds. With ram air as the inflow source, we expect the time constant to increase because ram air inflow does not supply air at as great a rate as the TCs. But what was unexpected was the time constant increase from TC inflow/SEV closed to TC inflow/SEV open, runs 5 to 8. This behavior was further demonstrated in runs 6 and 9 when the time constants increased from an average of 210 to 348 seconds respectively. As the total aperture for smoke removal increased, it actually took longer for the smoke levels to dissipate.

6.3.4 Explanation. One explanation for this phenomenon is that normal cabin air flow stagnated around the sensors due to airflow out the SEV. Figure 6-1 depicts the interior of the C-18

fuselage detailing the pressurization system supply ductwork and outflow valves. In the bottom right corner is a cross section of the fuselage and inflow/outflow points.

Figure 6-2 depicts an enlarged cross section of the fuselage and the relative positions of the SEV and data sensors two and three. This figure shows that when the SEV is closed, airflow circulates around the sensors and clears the cabin air.

Figure 6-3 shows the same cross section as Figure 6-2 except that the SEV is open. Depicted is the airflow pattern that is believed to have occurred. It was theorized that the draw of the SEV was so great that it pulled the majority of the air from the supply duct in the top of the fuselage and vented it overboard, resulting in a lower than normal rate of flow past the sensors and out through the outflow valves. This circulation pattern would result in higher time constants for runs in which the SEV was open, as Table 6-3 indicates.

Figure 6-4 shows another theoretical airflow pattern where the draw of the SEV is so great that it is actually drawing air in through the outflow valves to be vented overboard by the SEV. This flow pattern could also increase the time constants, depending on the flow rates along the different paths.

6.4 SMOKE VISUALIZATION

In an effort to assess smoke flow patterns in close proximity to the SEV, the valve was opened and the smoke was generated forward, aft, above, and below the SEV to a distance of 10 feet. From each position, smoke contoured towards the SEV and was drawn overboard. Although the light sensor data did not support the assertion that the SEV cleared smoke from the cabin more quickly than an aircraft without a SEV, this smoke visualization provided extremely valuable information on the ability of the SEV to vent smoke from the cabin.

6.5 CONSIDERATIONS FOR FURTHER INVESTIGATIONS

Modified Outflow Valve. The C-18/B-707 has three outflow valves on the underside of the aircraft as shown in Figure 6-1. They have approximately the same size opening as the SEV used in this program. The SEV is essentially an aircraft outflow valve covered by a flat plate that can be extended into the slipstream. As described in paragraph 2.1, the SEV was not certified for pressurized flight as were the aircraft's outflow valves. The idea occurred of modifying an existing outflow valve by installing an extendable, hinged flat plate or panel on the exterior of the aircraft immediately upstream of the valve. The plate would be completely exterior to the aircraft and could be extended hydraulically, electrically or manually.

It is envisioned that in an emergency this modified outflow valve would draw smoke and fumes from the cabin at a greater rate than existing outflow valve designs. Since all airflow would still exit the aircraft through the outflow valves, existing

cabin airflow patterns would not be further complicated by a SEV as was done in this test. The air would simply move faster through the cabin.

Lack of sufficent smoke generating capability to fill the entire cabin volume in a timely manner generated the idea of using a smoke dam. If the smoke capability can't be increased, a solution would be to down-size the test area by blocking off portions of the cabin with a smoke dam. Air circulation patterns would have to be taken into account.

The major concepts involved in venting smoke are flow volume and flow pattern. The goal of any smoke venting system is to move the largest volume of clean air at the greatest rate throughout the entire pressurized area to clean out the smoke. Factors affecting volume and rate are: inflow type (TC, bleed, ram), pressurized vs unpressurized, outflow valve size and SEV size. Factors affecting the flow pattern are: location of cabin air inlets and outlets, and rates of airflow. These concepts must be throughly understood to design and build an effective smoke venting system.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 1: The SEV and instrumentation as configured in this test did not completely satisfy the test objective as described in paragraph 1.2. However, as shown during the event described in paragraph 6.4, the SEV did vent smoke.

Conclusion 2: From the data collected (see Table 6-1), SEV position #7, 34 degrees open, created the maximum pressure differential.

Conclusion 3: The Rosco smoke generator was easy to use. The smoke generated caused no ill effects to personnel on the aircraft.

Conclusion 4: An open SEV vents smoke as evidenced by the demonstration described in paragraph 6.4.

Conclusion 5: When the SEV was opened, in addition to normal aircraft inflow/outflow, the smoke cleared more slowly at sensors 2 and 3. This was opposite from what was expected.

Discussion: This behavior was attributed to the disrupted airflow patterns within the cabin as discussed in paragraph 6.3.4.

Conclusion 6: The test design and instrumentation often gave unreliable results and made assessing the SEV's performance difficult.

Discussion: This test repeated no data runs due to time and money constraints. Too much was attempted in too little time. Perhaps holding all but one variable constant to ascertain the effectiveness of the SEV for a baseline condition rather than setting out to determine its performance in the various inflow/outflow/SEV configurations would have been a more prudent course of action.

Recommendation: Each run should be repeated at least once to increase the confidence in the results. Other methods which duplicate data and increase reliability such as instrumenting the SEV with multiple pressure sensors and placing a Hot Wire Anemometer in the valve throat, should be explored.

Conclusion 7: Too few sensors were used and they were located incorrectly to monitor smoke density throughout the cabin.

Discussion: In retrospect, for the SEV location selected in this test, the sensors appear to have been located incorrectly to accurately determine average cabin smoke levels.

Conclusion 8: The most notable information from the plots made of runs 5 through 13 (Figures A-1 through A-14), indicates that although smoke dissipated, the degree to which the SEV improves upon normal flight manual procedures is difficult to assess without computation of smoke-clearing time constants.

Conclusion 9: Flight limits on the SEV prevented data collection from the aircraft's full airspeed and altitude envelope.

Discussion: Due to the fact that the SEV was certified for less than the entire flight envelope (see paragraph 2.1), this test flight was not conducted throughout all conditions in which the SEV would be used operationally.

Recommendation: Further testing should be done in a more complete manner to include a pressurized aircraft and a range of C-18 airspeeds and altitudes.

Conclusion 10: Light sensor emitter and receptor design and lack of postflight sensor calibration may have caused some data scatter.

Discussion: The light sensor baffle employed in this test may not have negated the effects of stray ambient light in and near the test section. Light scattering could have occurred in this test when ambient cabin light or sunlight struck smoke particles in the test section. Some light could have been scattered toward the receptor photoelectric cell and thereby skewed the results.

Recommendation: Future testing should analyze the emitter/receptor used in this test in a smoke-filled environment to determine if the scattering of direct sunlight in the test section is a factor.

Discussion: Light sensors were calibrated prior to flight testing as described in paragraph 3.1.2. Due to time constraints and the need to get the FAA test equipment disassembled, packed and on its way to another test, the calibration of light sensors was not checked after the flight. Performing this task would have increased the confidence in the data.

Recommen. tion: Time should be allowed for the light sensors t. be calibrated both before and after the flight.

Conclusion 11: T' : smoke moved in clumps like patchy fog and in a clo. ike manner.

Discussion: Wh.n smoke was being generated during runs 8-13, pressurization system inflow was filling the cabin with clean air while cabin air vented overboard through the outflow valves. Because air was being pumped through the cabin continuously, the smoke generated did not completely mix with ambient air in the short time from beginning to end of smoke generation. As a result, the smoke moved in clouds.

Recommendation: No clean air inflow or outflow should be allowed until the test area is evenly filled with smoke and ready for testing.

Conclusion 12: The smoke generator employed did not have the capacity to fill the entire test area in a timely manner.

Discussion: Testing described in this report used four sets of smoke sensors evenly spaced along 60 feet of cargo cabin area. The rearward two sets of sensors never saw high enough levels of smoke to render their data useful.

Recommendation: In future testing, either a higher capacity smoke generator, multiple generators or a smoke dam should be employed.

Conclusion 13: Airflow patterns within the cabin were poorly understood during the design and conduct of the test.

Discussion: Stagnating airflow in the area of the sensors appears to have dramatically skewed the data. Visualizing and understanding flow patterns are crucial to further testing. One approach might be to release smoke near the distribution outlet with a smoke wand, and monitor flow patterns. A Hot Wire Anemometer could be used to assess flow rates at specific points.

Recommendation: Smoke wands or some other suitable flow visualization method should be employed in close proximity to the SEV, pressurization system distribution and collection outlets and anywhere flow information is desired to assess localized flow patterns in various SEV/inflow/outflow configurations.

Conclusion 14: Selection of SEV location was performed through a mathematical analysis of the pressure coefficients surrounding the aircraft.

Recommendation: Flight testing of the SEV in different locations on the aircraft to verify the optimum position should be accomplished.

Conclusion 15: Airflow patterns through the SEV and around the exterior of the SEV were not completely understood.

Discussion: Many questions regarding pressures and airflow rates in and around the SEV could be answered by installing a tufted SEV and instrumentation in some type of simulated fuselage section and testing it in a wind tunnel.

Recommendation: Wind tunnel test a SEV using tufts, oilflow, smoke, pressure taps, and perhaps hot wire or laser doppler anemometry to characterize the flow through and around a SEV.

REFERENCES

1. USAF C-141 Class A Mishap, 12 Jul 84.

2. Lancaster, P., and Salkauskas, K. Curve and Surface Fitting, Academic
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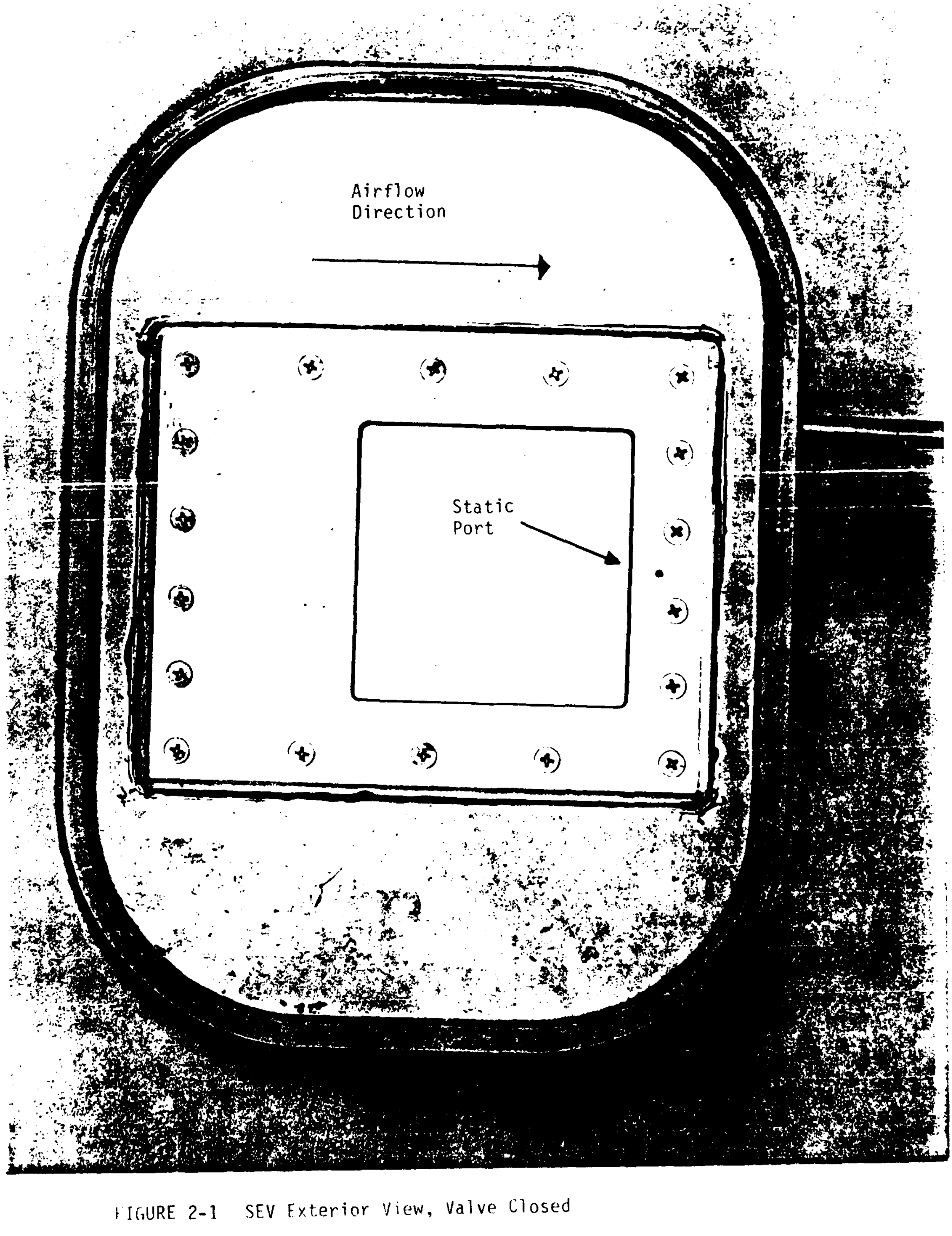


FIGURE 2-1 SEV Exterior View, Valve Closed

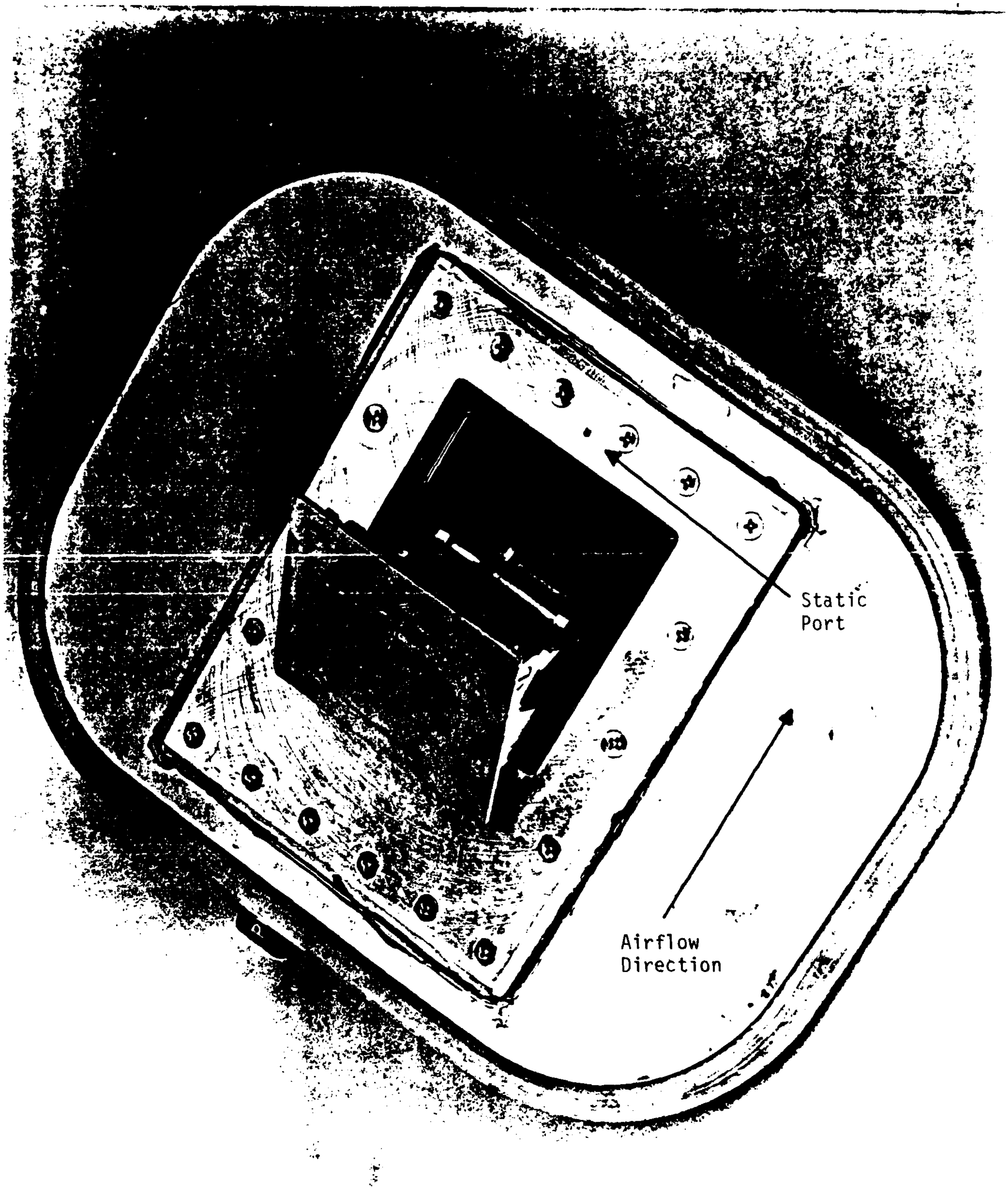


FIGURE 2-2 SEV Exterior View, Valve Open

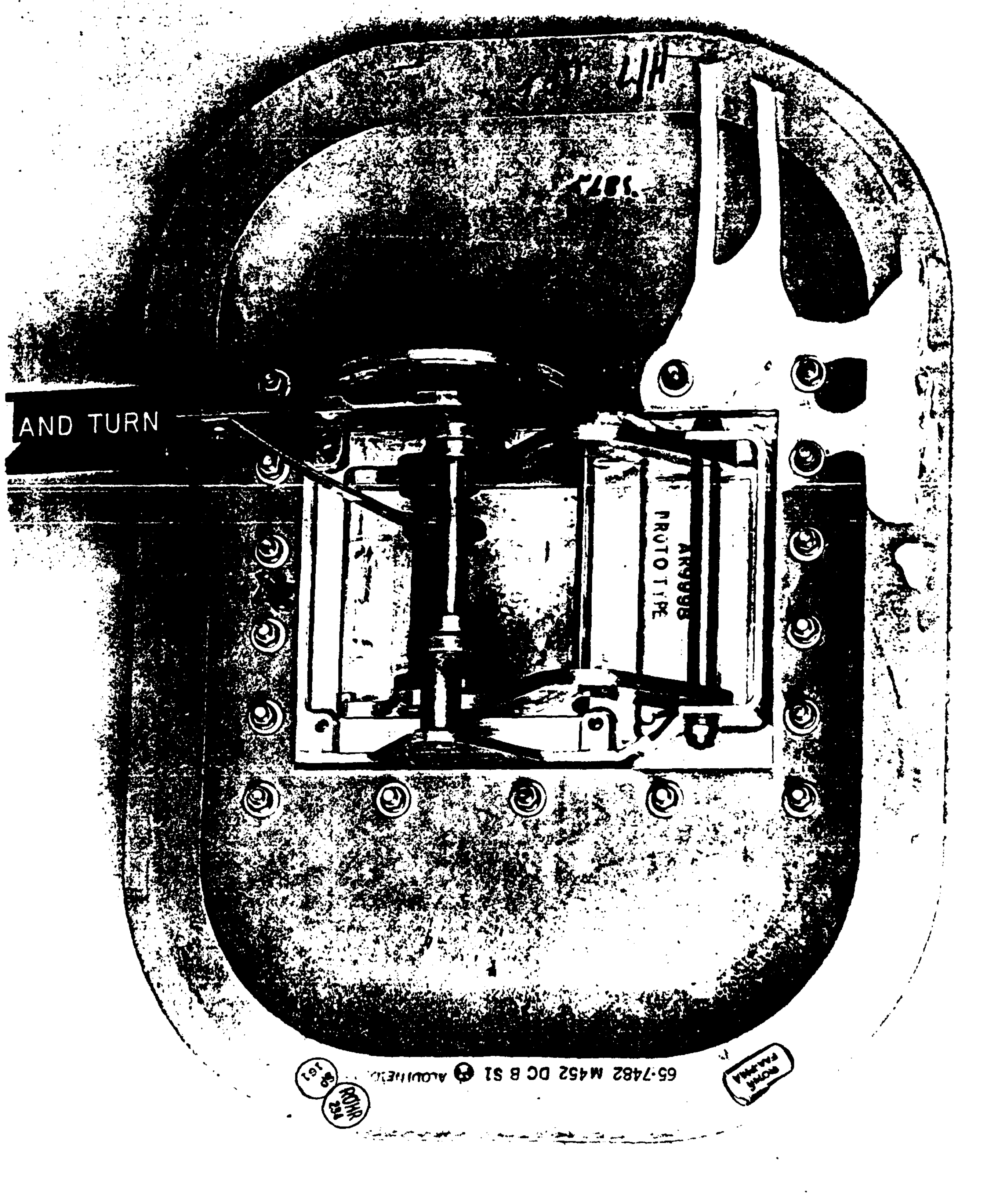


FIGURE 2-3 SEV Interior View, Valve Closed

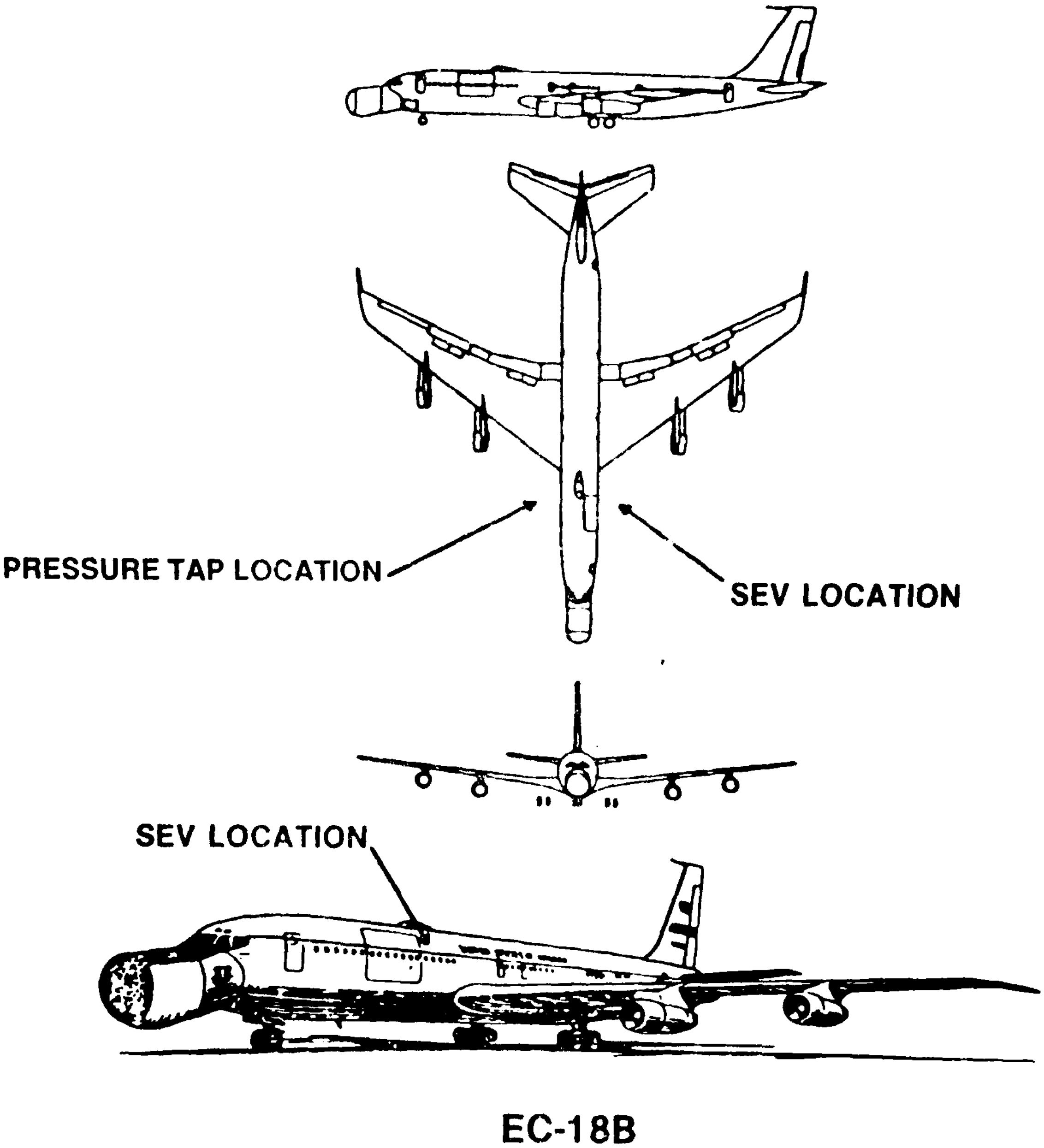


FIGURE 2-4 Exterior View of Aircraft

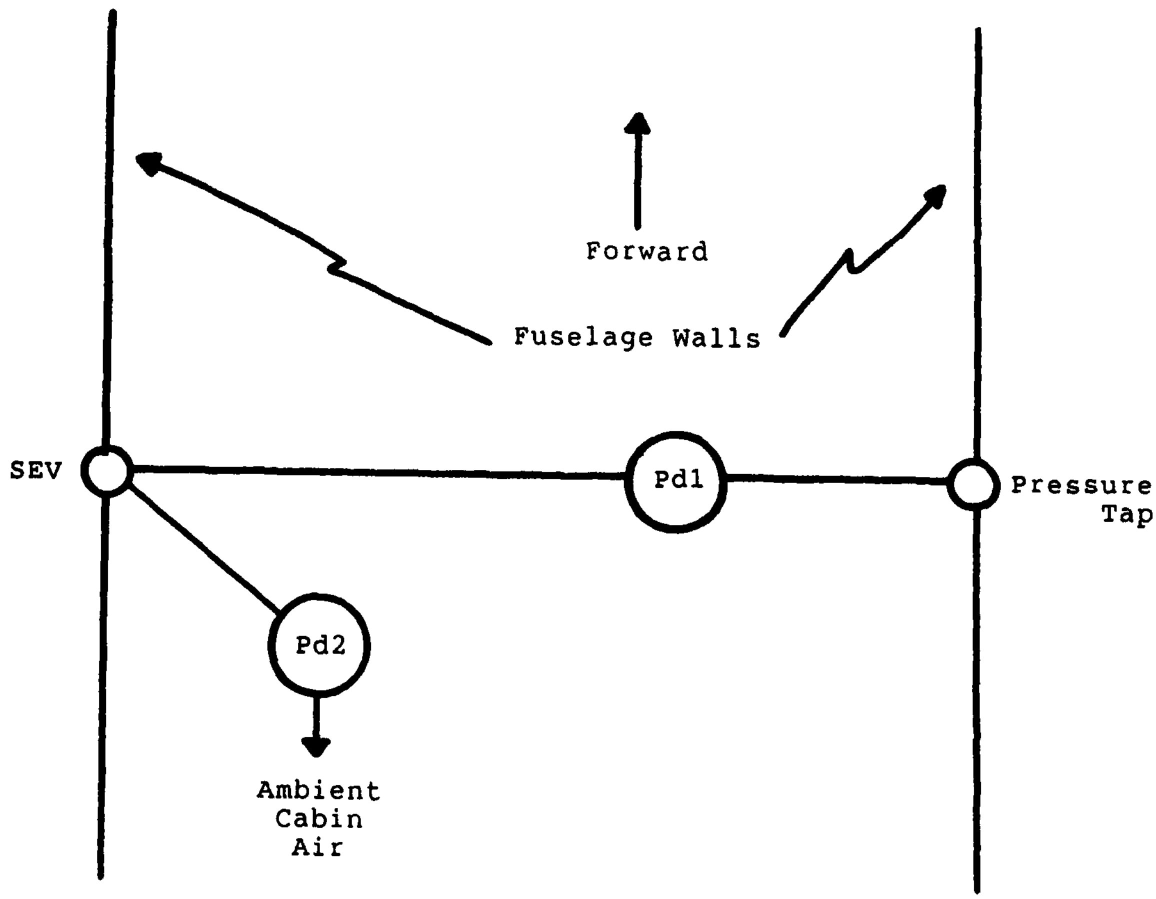


FIGURE 3-1, Differential Pressure Gauge Schematic

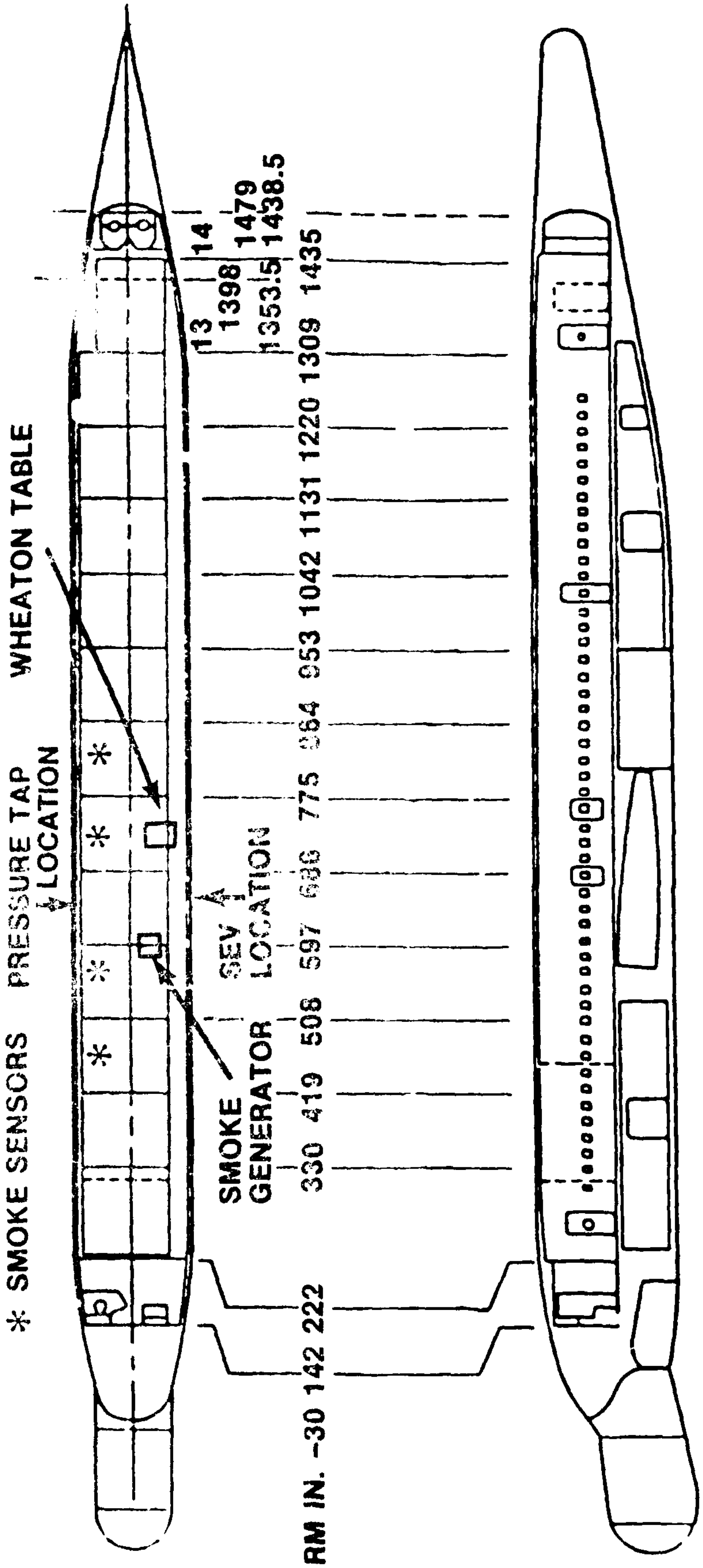


FIGURE 3-2 Interior Layout

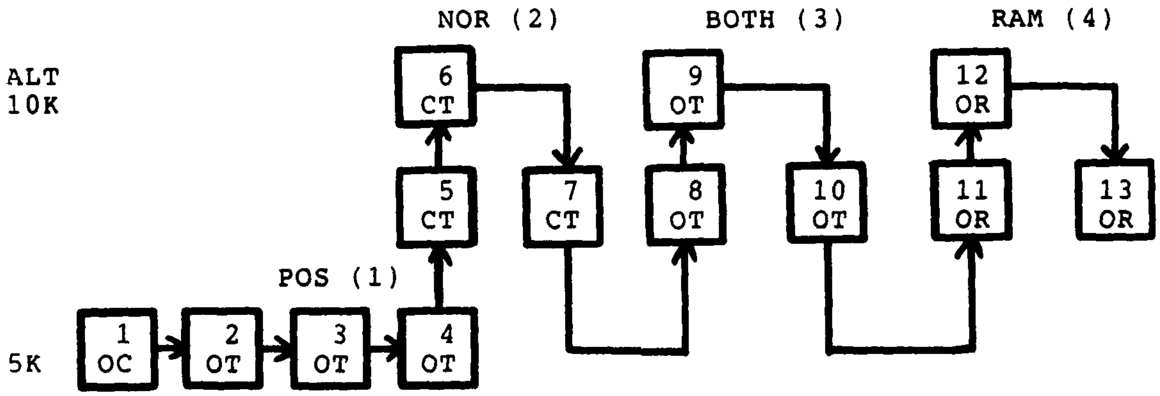


FIGURE 4-1, FLIGHT TEST CONDITIONS. For each condition (1-13), the first letter of the two letter code denotes the SEV position (O:Open, C:Closed). The second letter of the two denotes the type of inflow (T:Turbocompressor, R:Ram). POS (1), NOR (2), BOTH (3), and RAM (4) refer to the four sets of flight conditions being investigated in the test as described in paragraph 4.3.

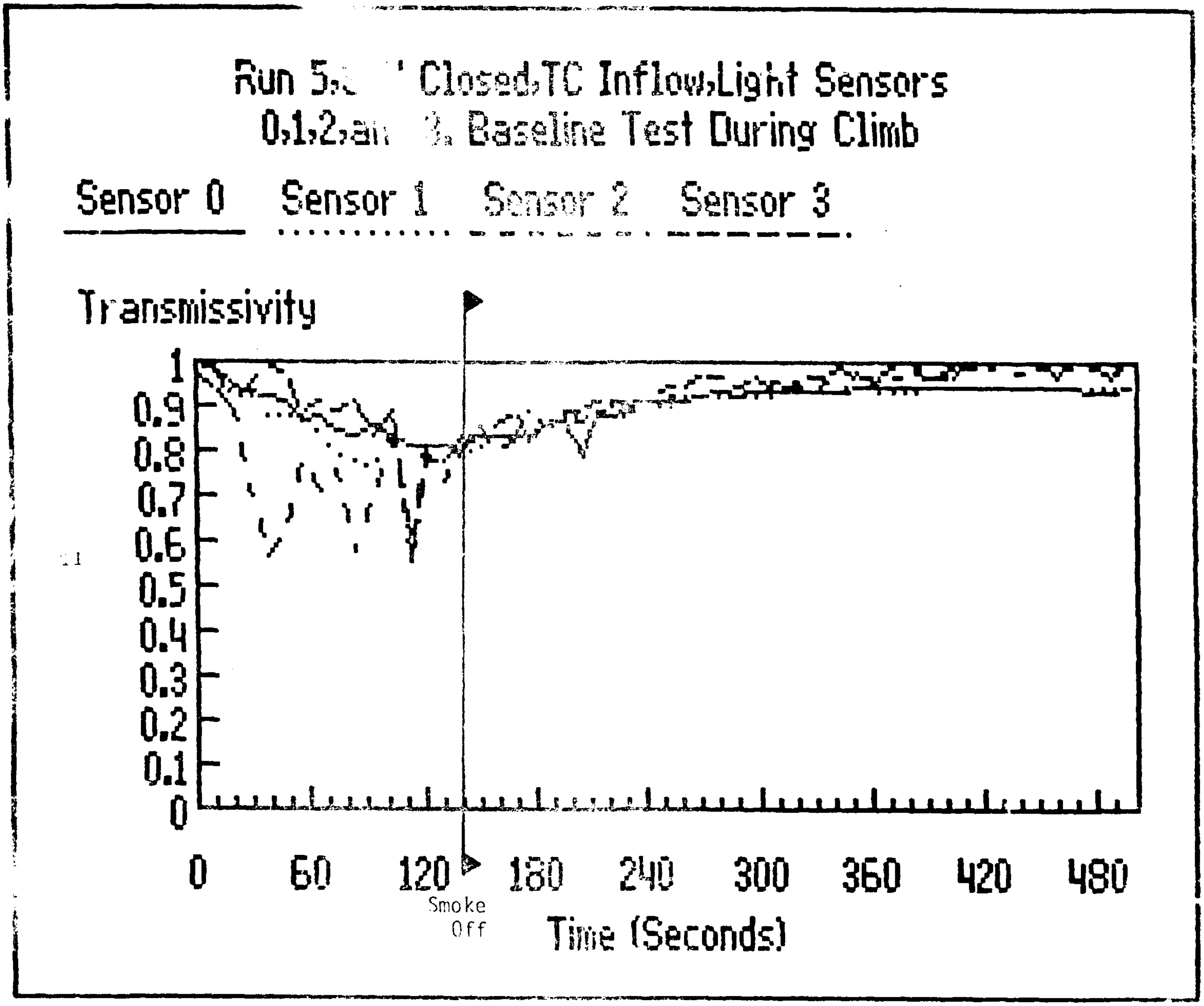


FIGURE 5-1 Sensor Data

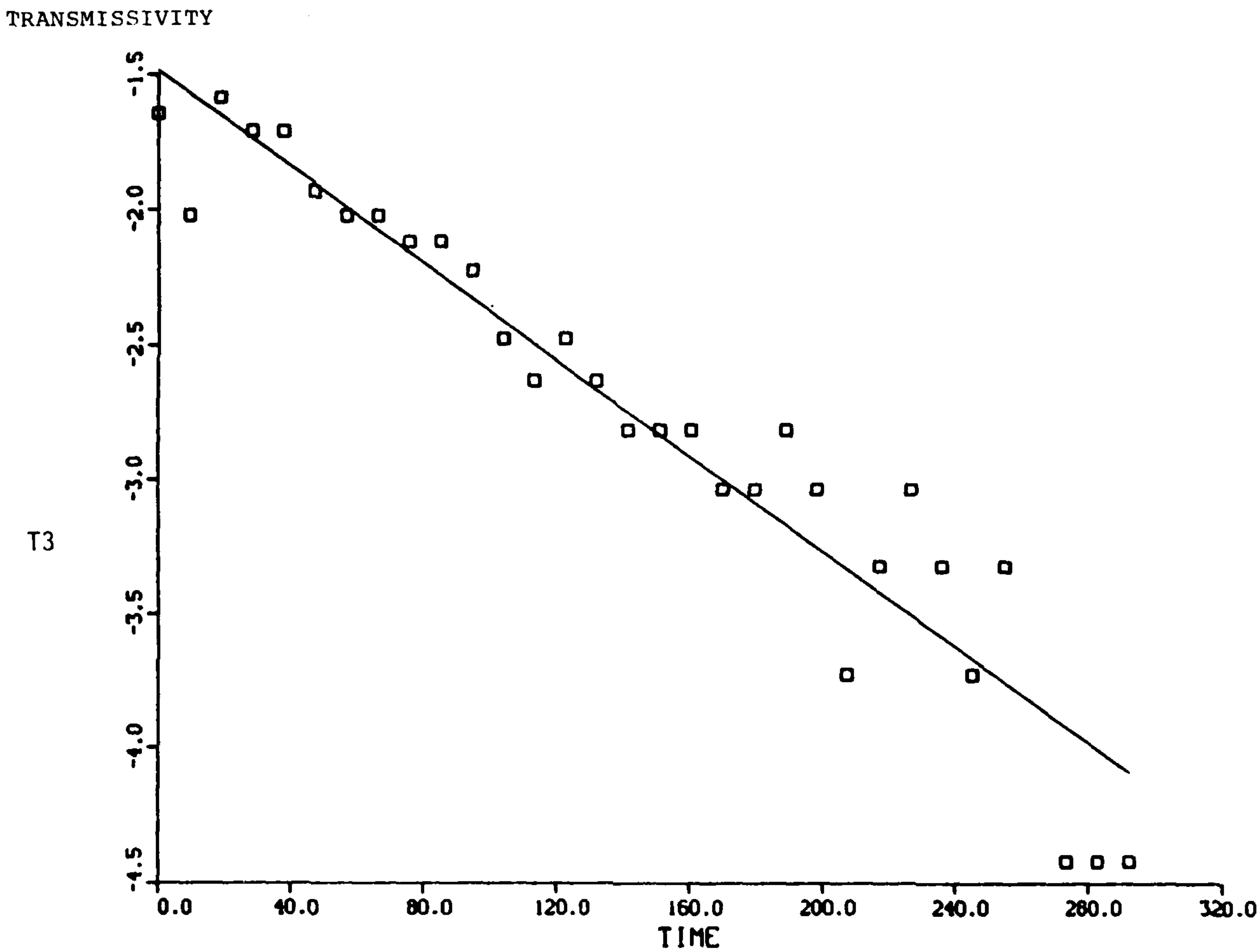


FIGURE 5-2 Natural Logarithm Plot of Data

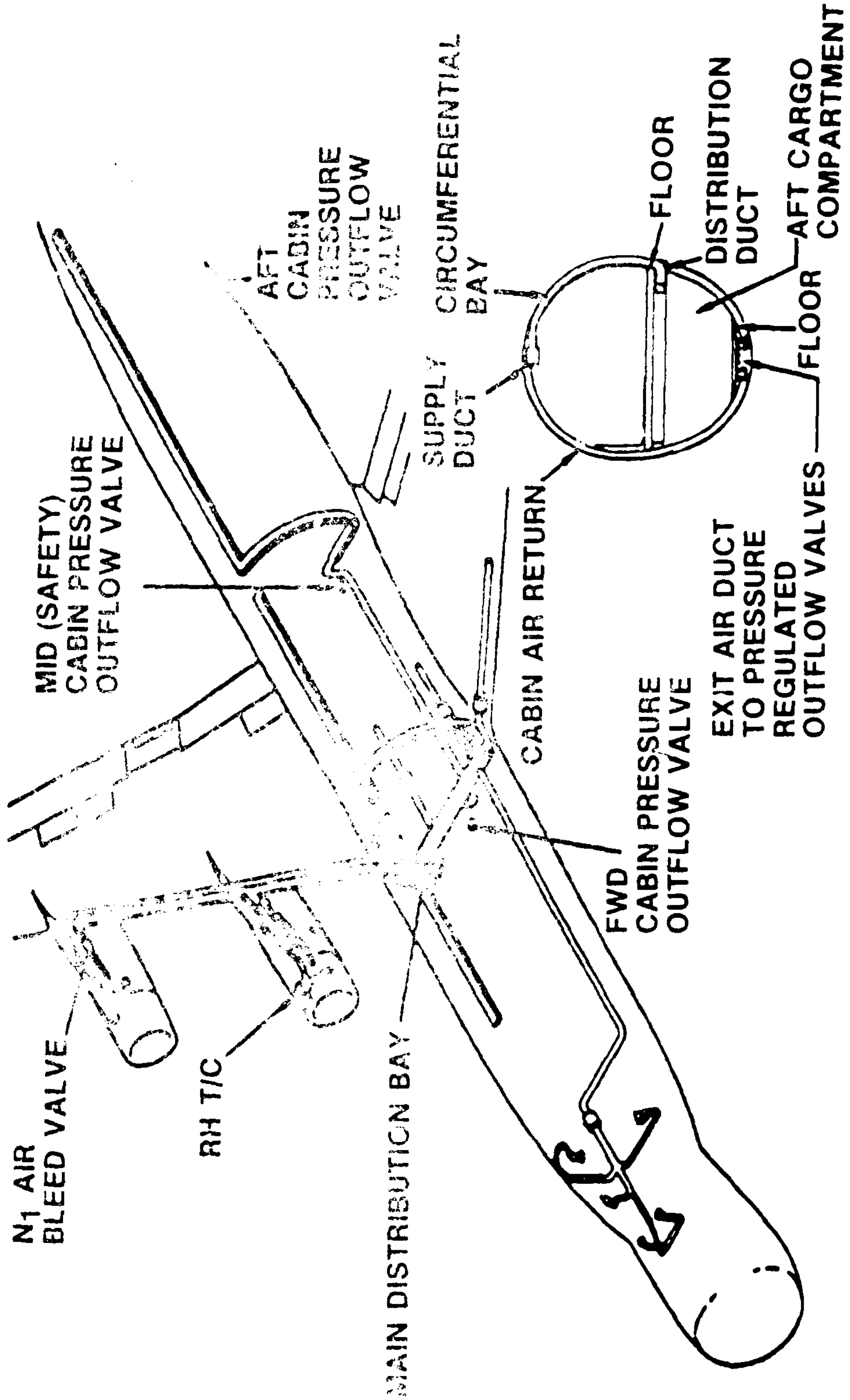


FIGURE 6-1 C-18 Pressurization System

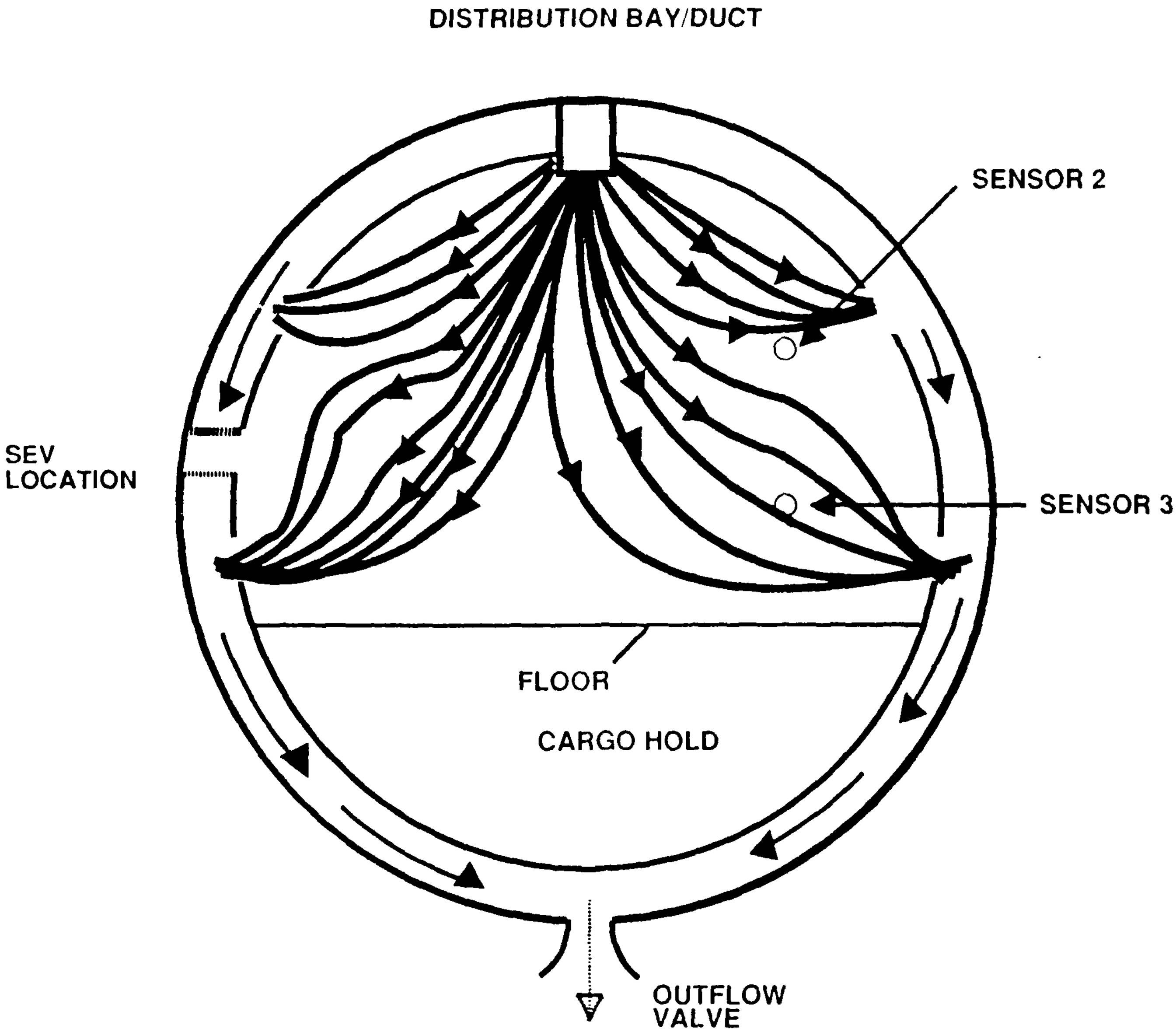


FIGURE 6-2 Cabin Airflow, SEV Closed

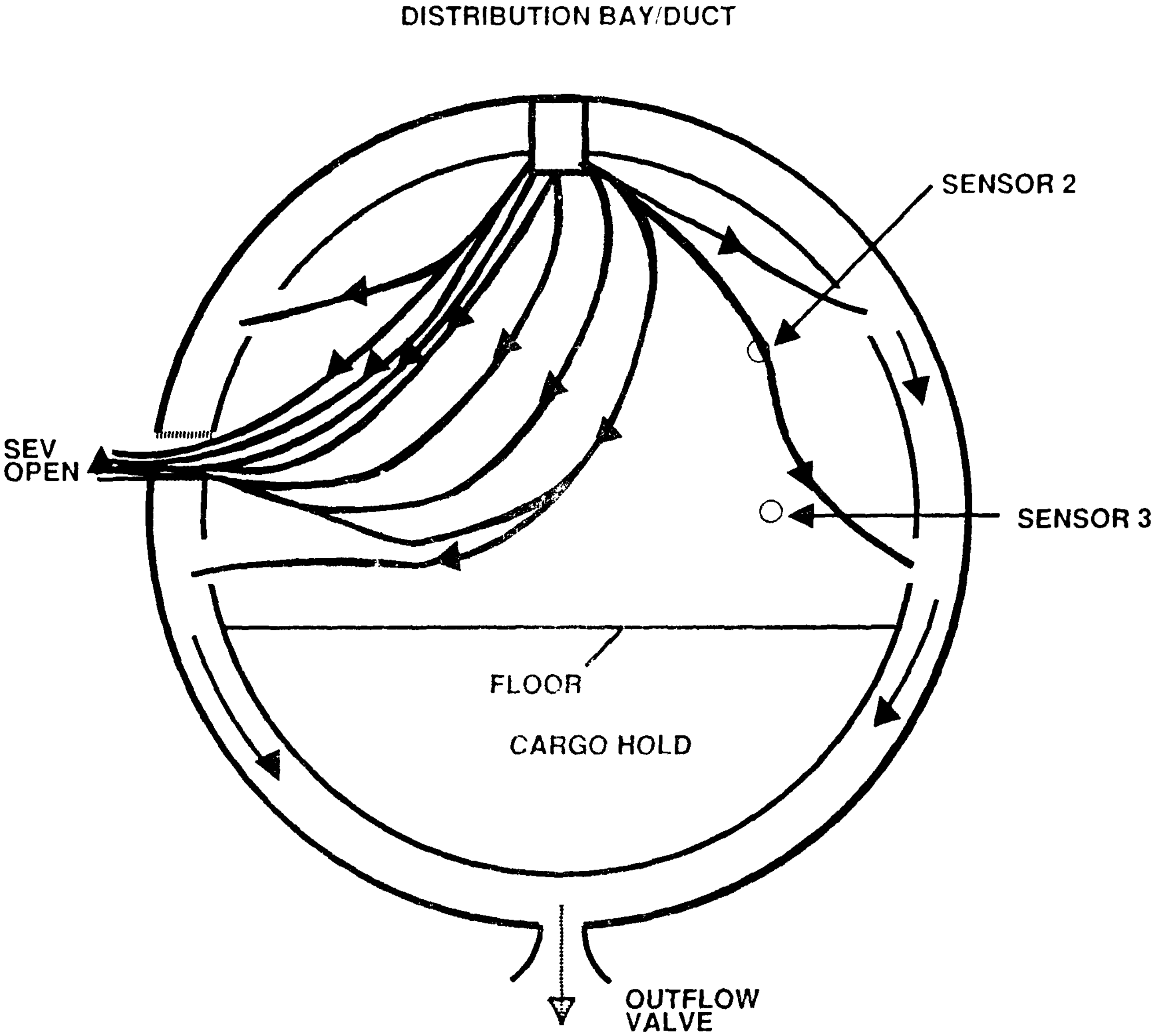


FIGURE 6-3 Cabin Airflow I, SEV Open

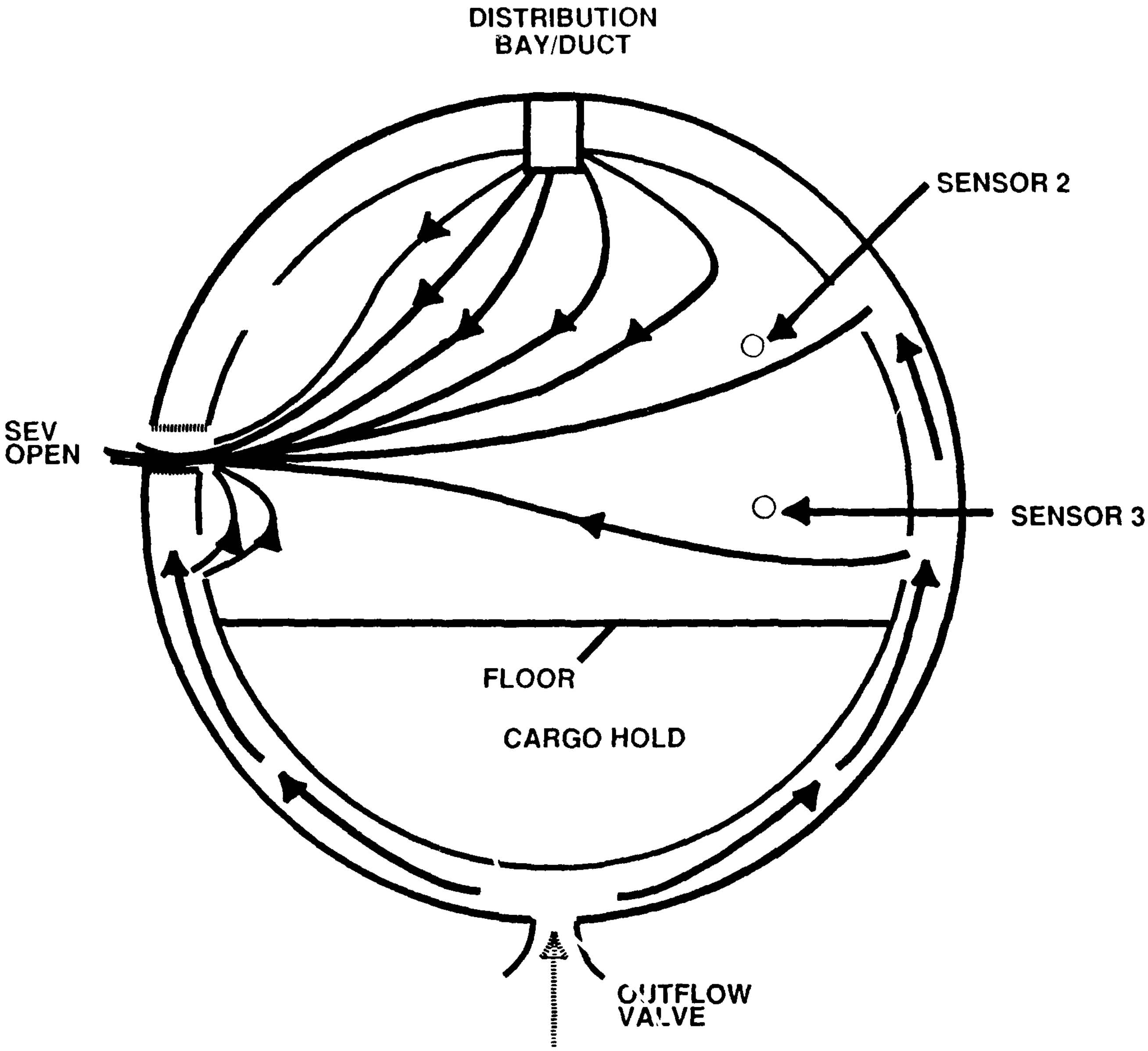


FIGURE 6-4 Cabin Airflow II, SEV Open

Run #	KIAS	Flight Mode	TC Inflow	Ram Air Inflow	SEV Pos #
1	250	Level 5K'	closed	closed	9
2	250	Level 5K	open	closed	2,4,7,9
3	200	Level 5K	open	closed	2,4,7,9
4	APP	Level 5K	open	closed	2,4,7,9
5	250	Climb	open	closed	0
6	250	Level 10K'	open	closed	0
7	250	Descent	open	closed	0
8	250	Climb	open	closed	7
9	250	Level 10K'	open	closed	7
10	250	Descent	open	closed	7
11	250	Climb	closed	open	7
12	250	Level 10K'	closed	open	7
13	250	Descent	closed	open	7

TABLE 4-1, Flight Test Parameters

RUN/SEV POS#	Pd1 SEV-PRESSURE TAP PRS (Inches Water)	Pd2 SEV-CABIN PRS (Inches Water)
1/0	-3.0	-0.9
1/9	-3.9	-0.5
2/0	-2.8	-6.0
2/2	-4.5	-4.9
2/4	-9.3	-10.1
2/7	-15.0	-19.0
2/9	-14.3	-16.3
3/0	-2.2	-8.1
3/2	-2.4	-8.1
3/4	-8.1	-13.2
3/7	-12.2	-16.8
3/9	-11.2	-17.2
4/0	-1.5	-6.5
4/2	-0.9	-7.7
4/4	-5.6	-11.6
4/7	-6.9	-11.8
4/9	-6.7	-11.6

TABLE 6-1, SEV Position Optimization Data

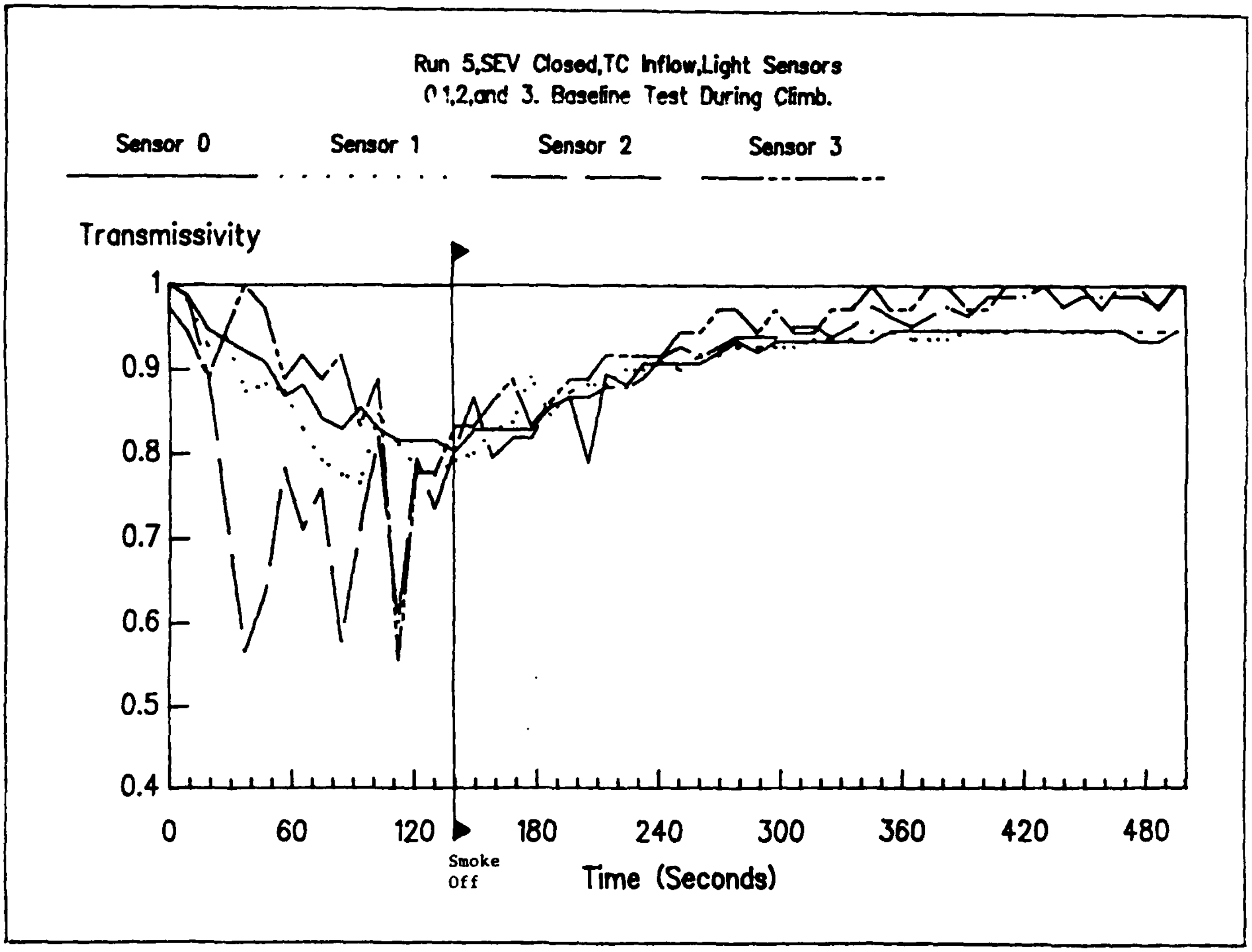
RUN/SEV POS#		Pd1 SEV-PRESSURE TAP PRS (Inches Water)		Pd2 SEV-CABIN PRS (Inches Water)
5/0		-3.1	Smoke on	-8.1
5/0	Climb	-2.9	Smoke off	-6.1
5/0		-2.9	End run	-6.2
6/0		-3.0	Smoke on	-6.2
6/0	Cruise	-3.0	Smoke off	-6.1
6/0		-3.0	End run	-6.5
7/0		-3.0	Smoke on	-6.5
7/0	Descent	-3.0	Smoke off	-4.0
7/0		-3.0	End run	-4.6
8/0		-3.0	Smoke on	-4.8
8/7	Climb	-16.5	Valve open	-17.5
8/0			Not collected	
9/0		-3.0	Smoke on	-5.8
9/7	Cruise	-14.6	Valve open	-14.5
9/7		-15.0	In a right turn	-17.0
9/0			Not collected	
10/0		-3.0	Smoke on	-5.5
10/7	Descent	-14.5	Valve open	-14.3
10/0		-3.1	End run	-3.6
11/0		-2.9	Smoke on	-1.5
11/7	Climb	-14.5	Valve open	-11.8
11/0		-3.0	End of run	-0.3
12/0		-3.0	Smoke on	-0.8
12/7	Cruise	-13.9	Valve open	-11.4
12/0		-3.0	End of run	-1.5
13/0		-3.0	Smoke on	-1.5
13/7	Descent	-14.0	Valve open	-10.5
13/0		-3.0	End of run	0.0

TABLE 6-2, SEV Pressure Data

(Sensor # 2 or 3)	Climb	Cruise	Descent
TC Inflow SEV Closed	Run 5 (#2) 112 (#3) 107	Run 6 (#2) 201 (#3) 219	Run 7 No Data
TC Inflow SEV Open	Run 8 (#2) 281 (#3) 268	Run 9 (#2) 346 (#3) 349	Run 10 (#2) 121 (#3) 181
RAM Inflow SEV Open	Run 11 (#2) 284 (#3) 555	Run 12 No Data	Run 13 (#2) 57 (#3) 234

TABLE 6-3

Smoke Decay Time Constants For Sensors 2 and 3



Run 5,SEV Closed,TC Inflow,Light Sensors
0,1,2,and 3. Baseline Test During Climb.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke Off
Time (Seconds)

FIGURE A-1

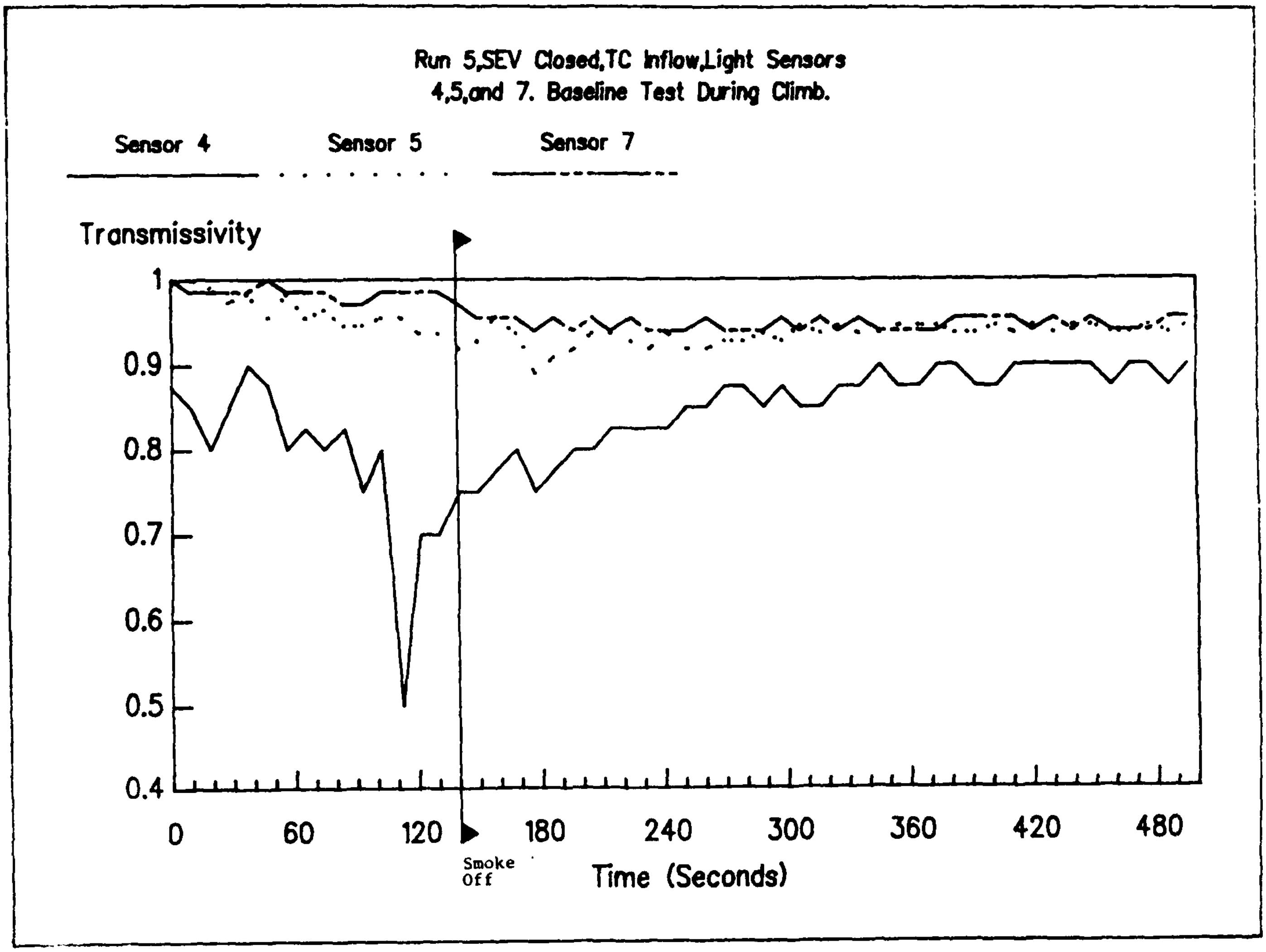
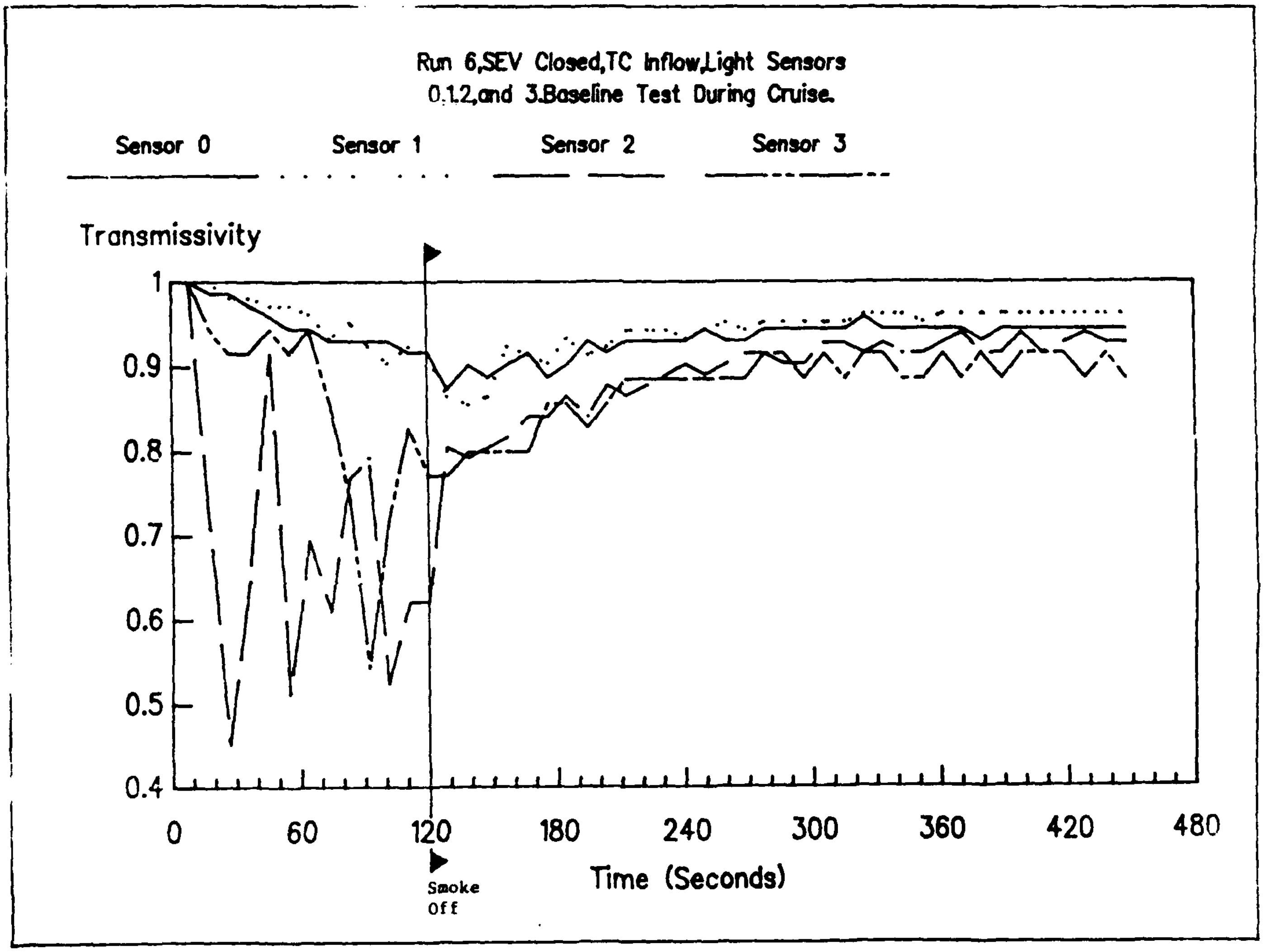

Run 5,SEV Closed,TC Inflow,Light Sensors
4,5,and 7. Baseline Test During Climb.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke Off
Time (Seconds)

FIGURE A-2



Run 6,SEV Closed,TC Inflow,Light Sensors
0,1,2,and 3.Baseline Test During Cruise.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Time (Seconds)
Smoke Off

FIGURE A-3

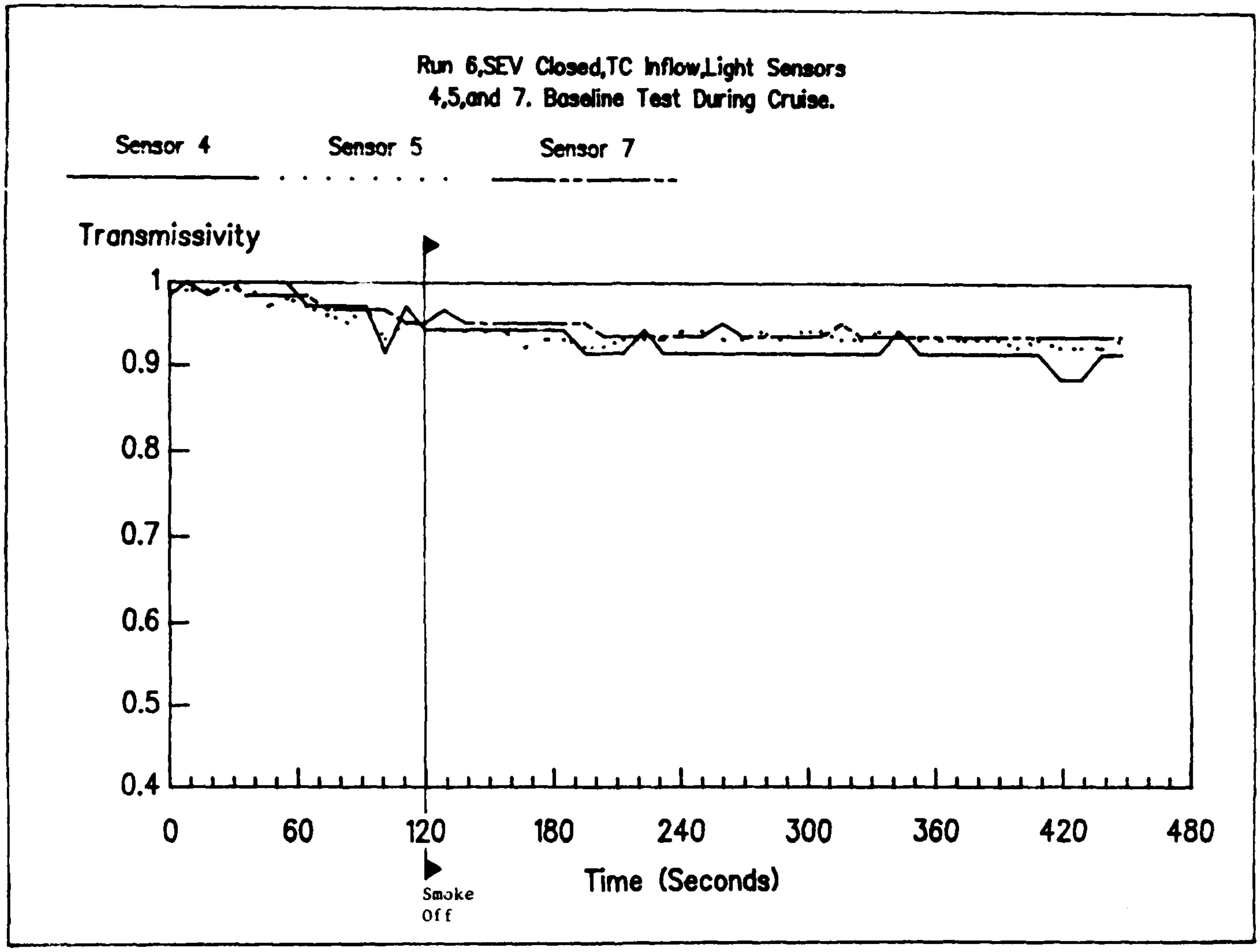
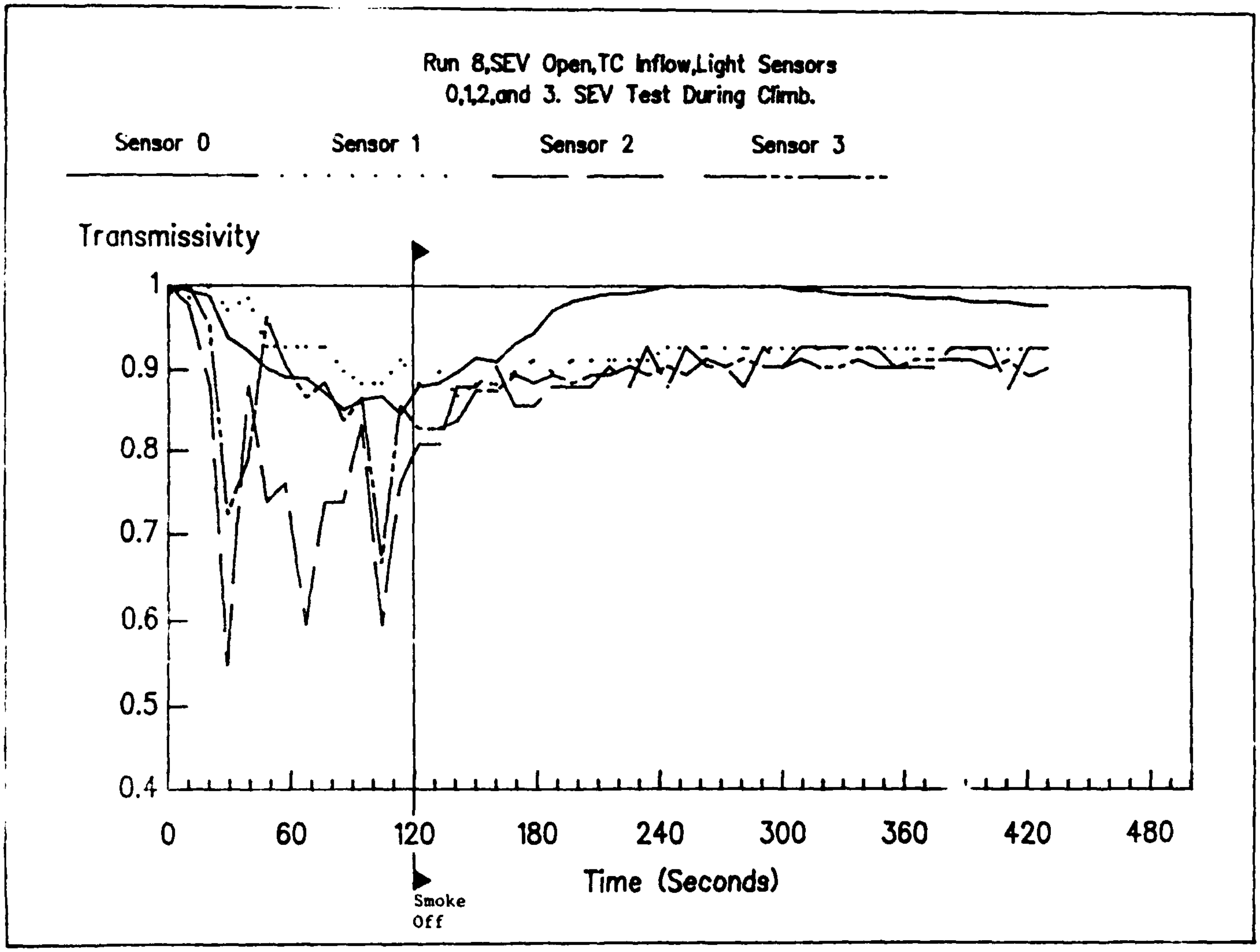
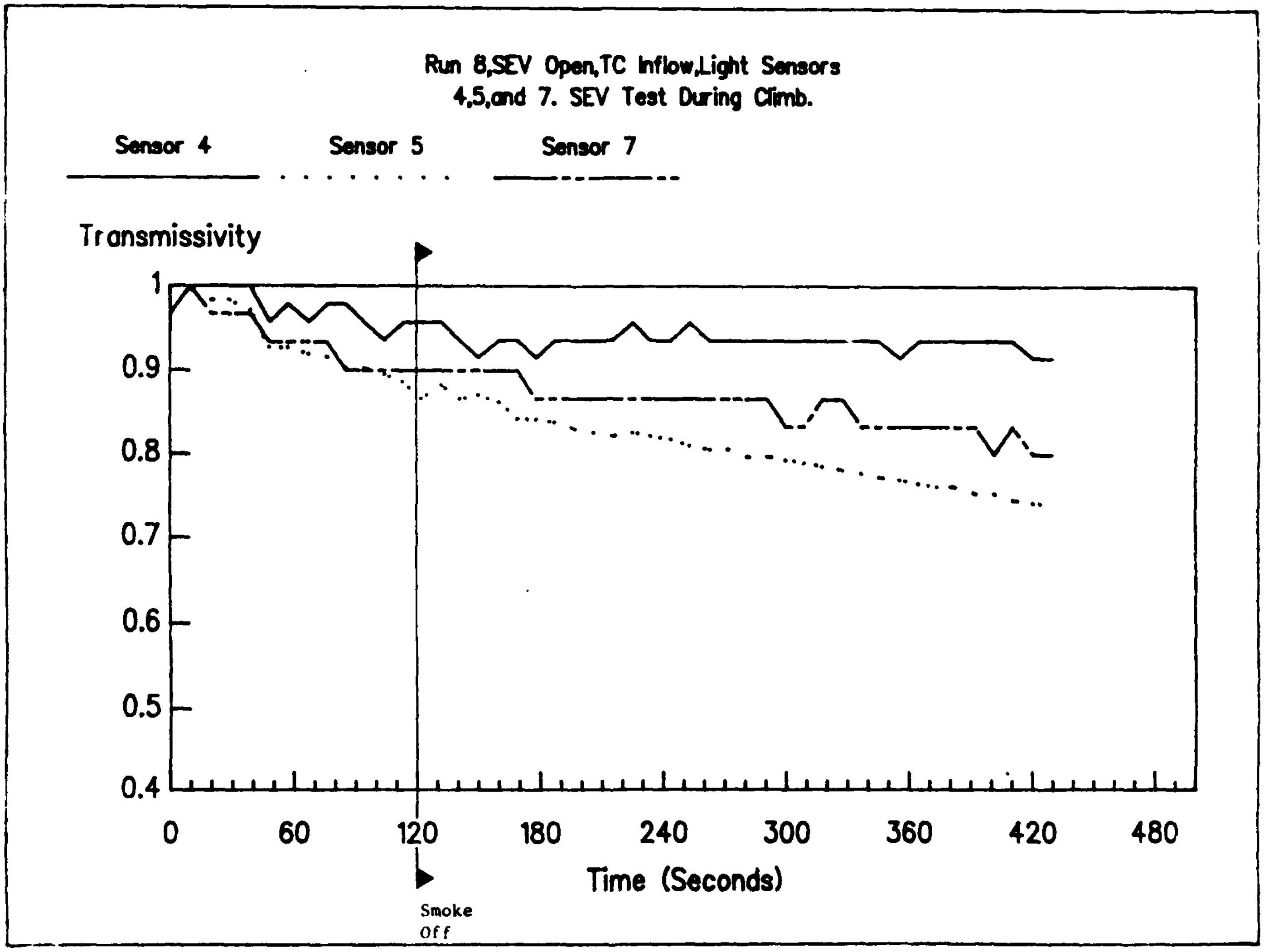

Run 6,SEV Closed,TC Inflow,Light Sensors
4,5,and 7. Baseline Test During Cruise.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Time (Seconds)
Smoke
Off

FIGURE A-4



Run 8,SEV Open,TC Inflow,Light Sensors
0,1,2,and 3. SEV Test During Climb.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Time (Seconds)
Smoke
Off

FIGURE A-5



Run 8,SEV Open,TC Inflow,Light Sensors
4,5,and 7. SEV Test During Climb.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Time (Seconds)
Smoke
Off

FIGURE A-6

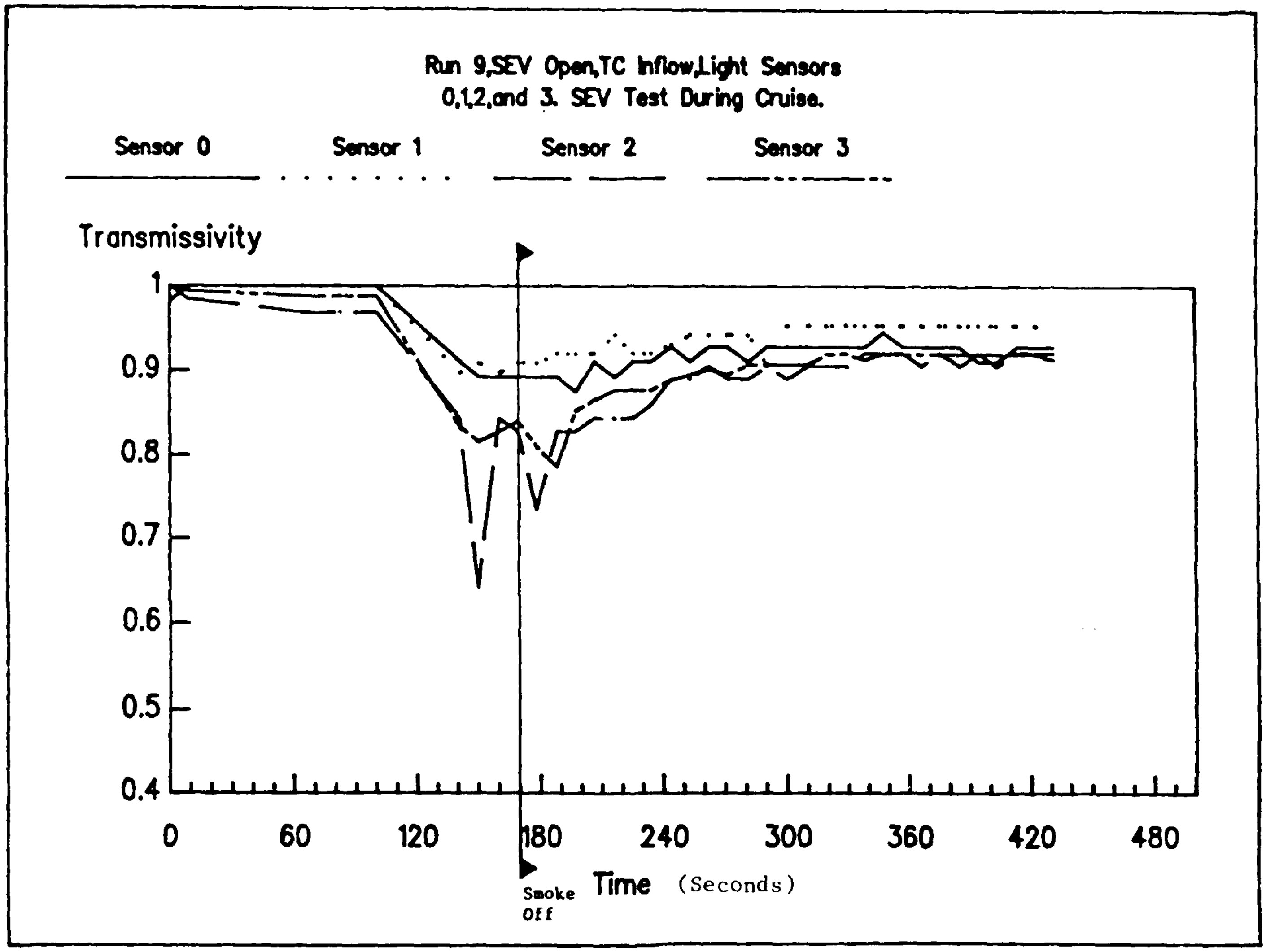

Run 9,SEV Open,TC Inflow,Light Sensors
0,1,2,and 3. SEV Test During Cruise.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke Off
Time (Seconds)

FIGURE A-7

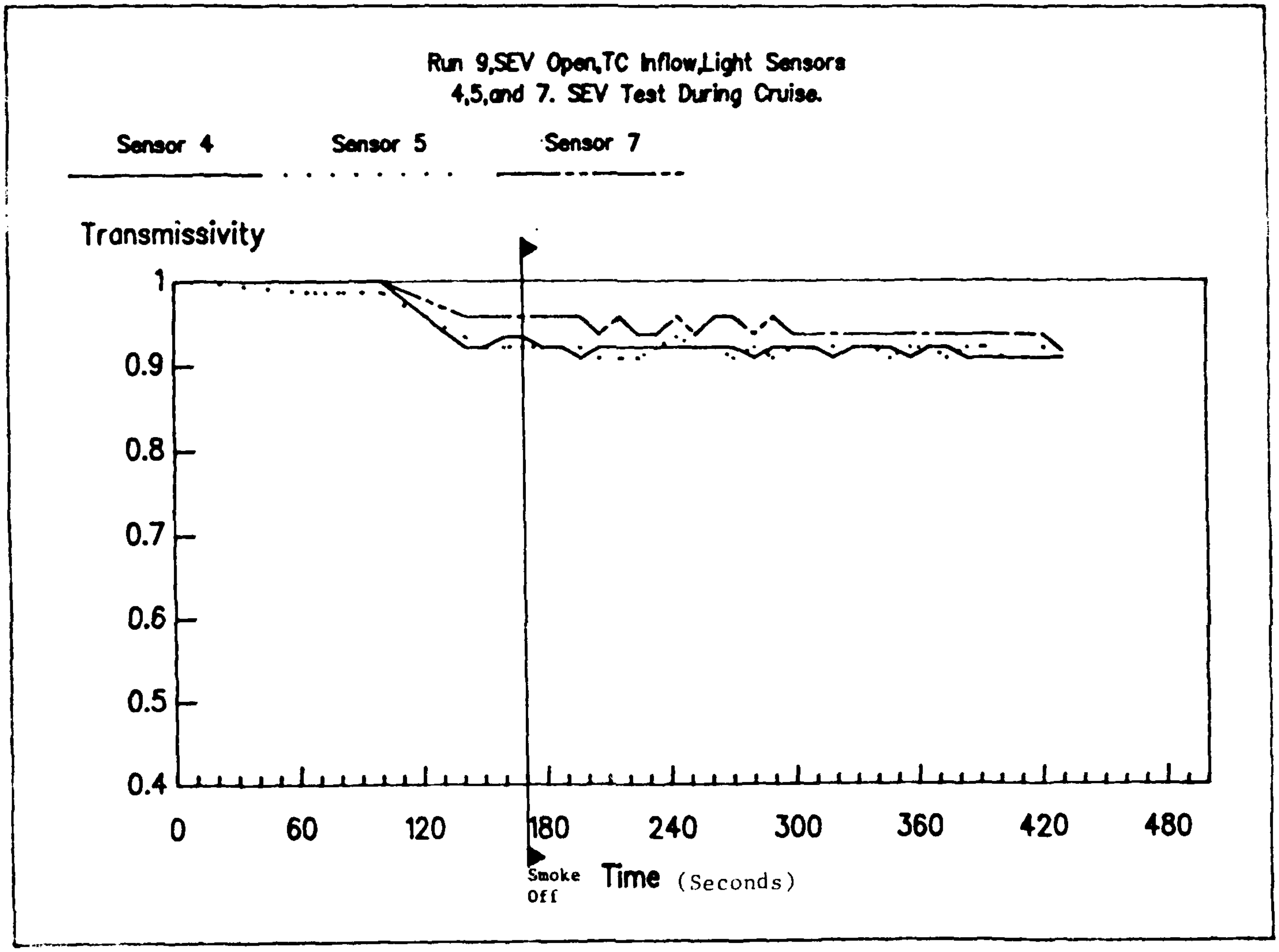

Run 9,SEV Open,TC Inflow,Light Sensors
4,5,and 7. SEV Test During Cruise.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke
Off
Time (Seconds)

FIGURE A-8

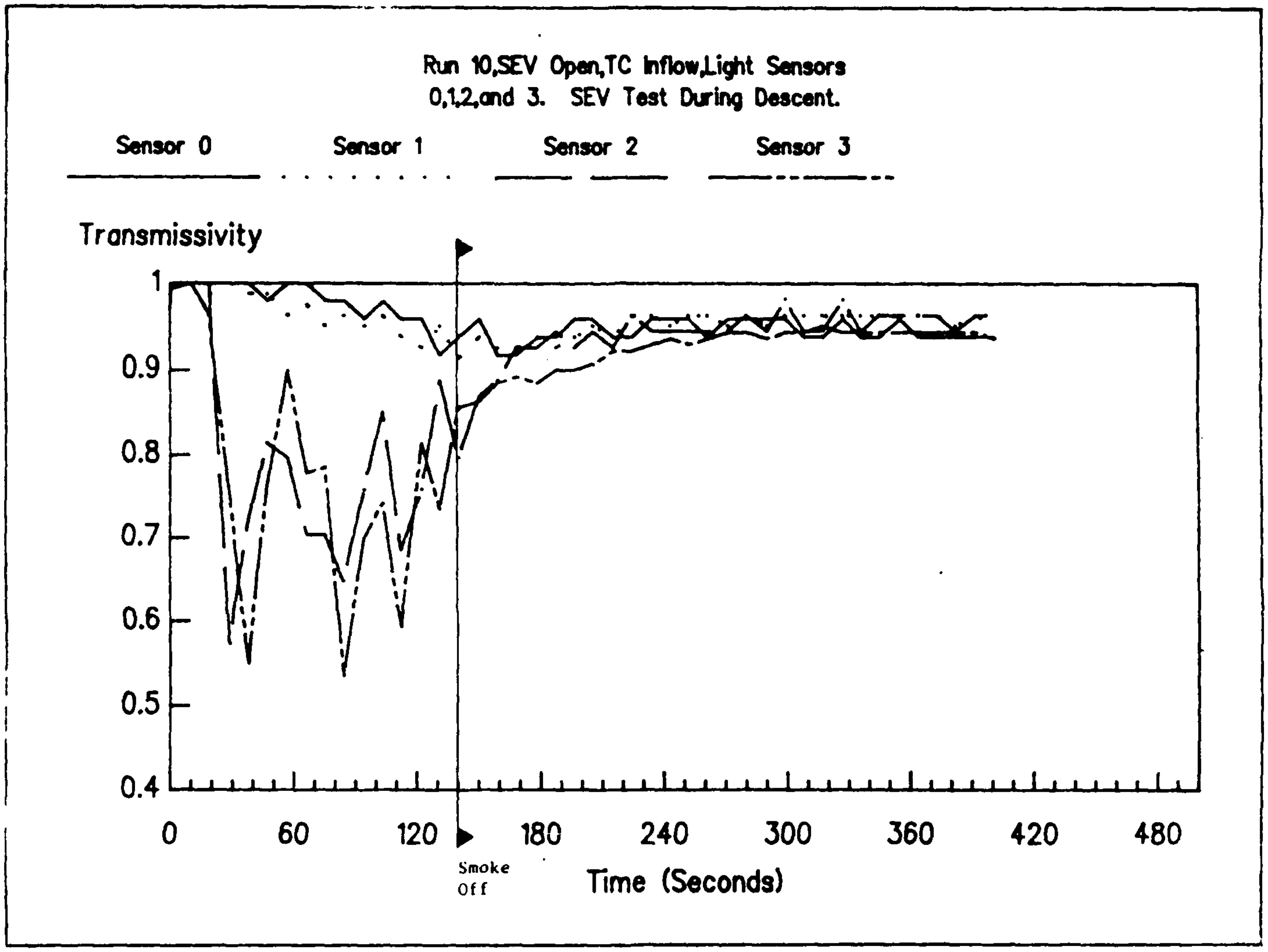
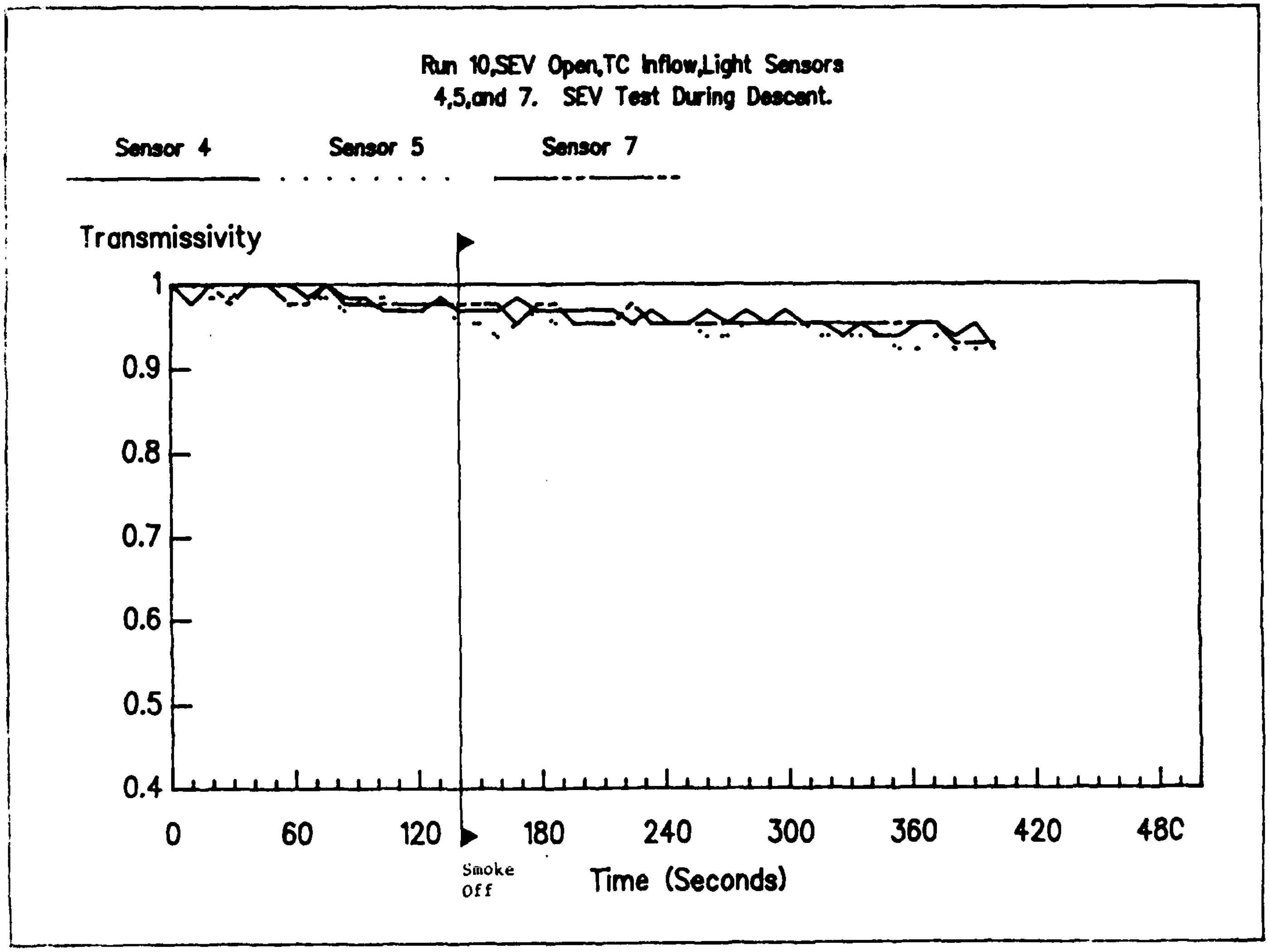
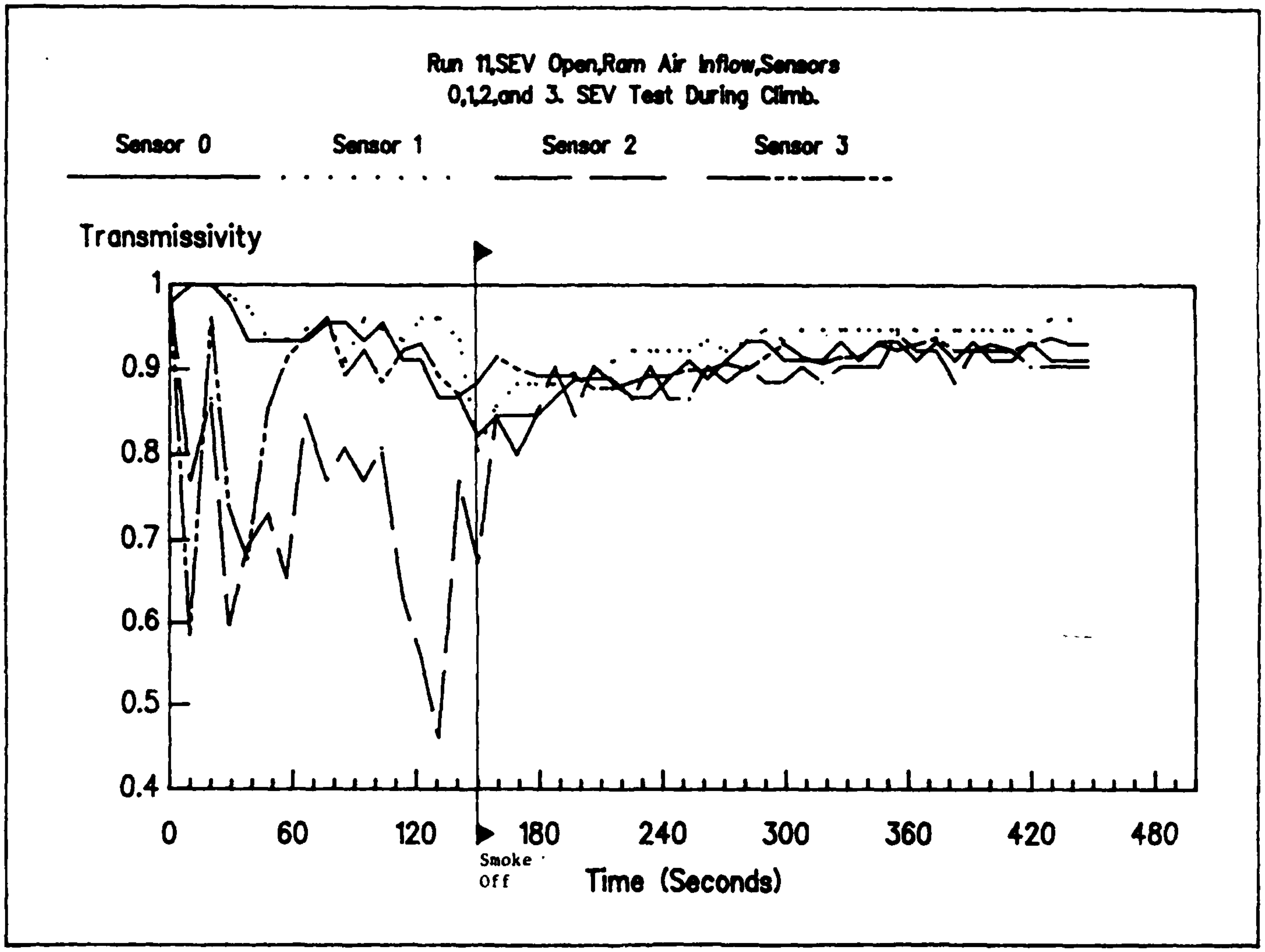

Run 10,SEV Open,TC Inflow,Light Sensors
0,1,2,and 3. SEV Test During Descent.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke Off
Time (Seconds)

FIGURE A-9



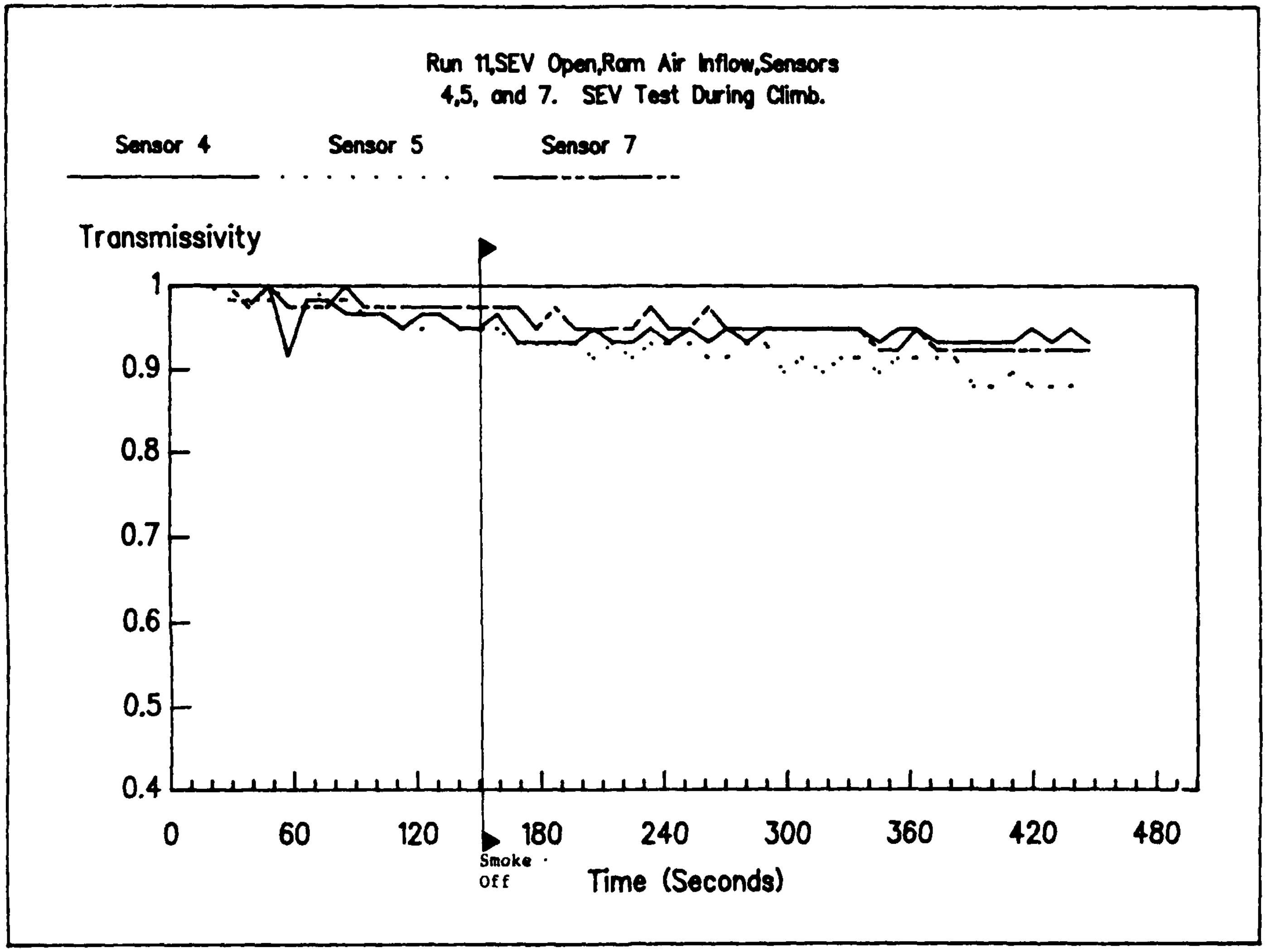
Run 10,SEV Open,TC Inflow,Light Sensors
4,5,and 7. SEV Test During Descent.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
48C
Smoke
Off
Time (Seconds)

FIGURE A-10



Run 11,SEV Open,Ram Air Inflow,Sensors
0,1,2,and 3. SEV Test During Climb.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke
Off
Time (Seconds)

FIGURE A-11



Run 11,SEV Open,Ram Air Inflow,Sensors
4,5, and 7. SEV Test During Climb.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke
Off
Time (Seconds)

FIGURE A-12

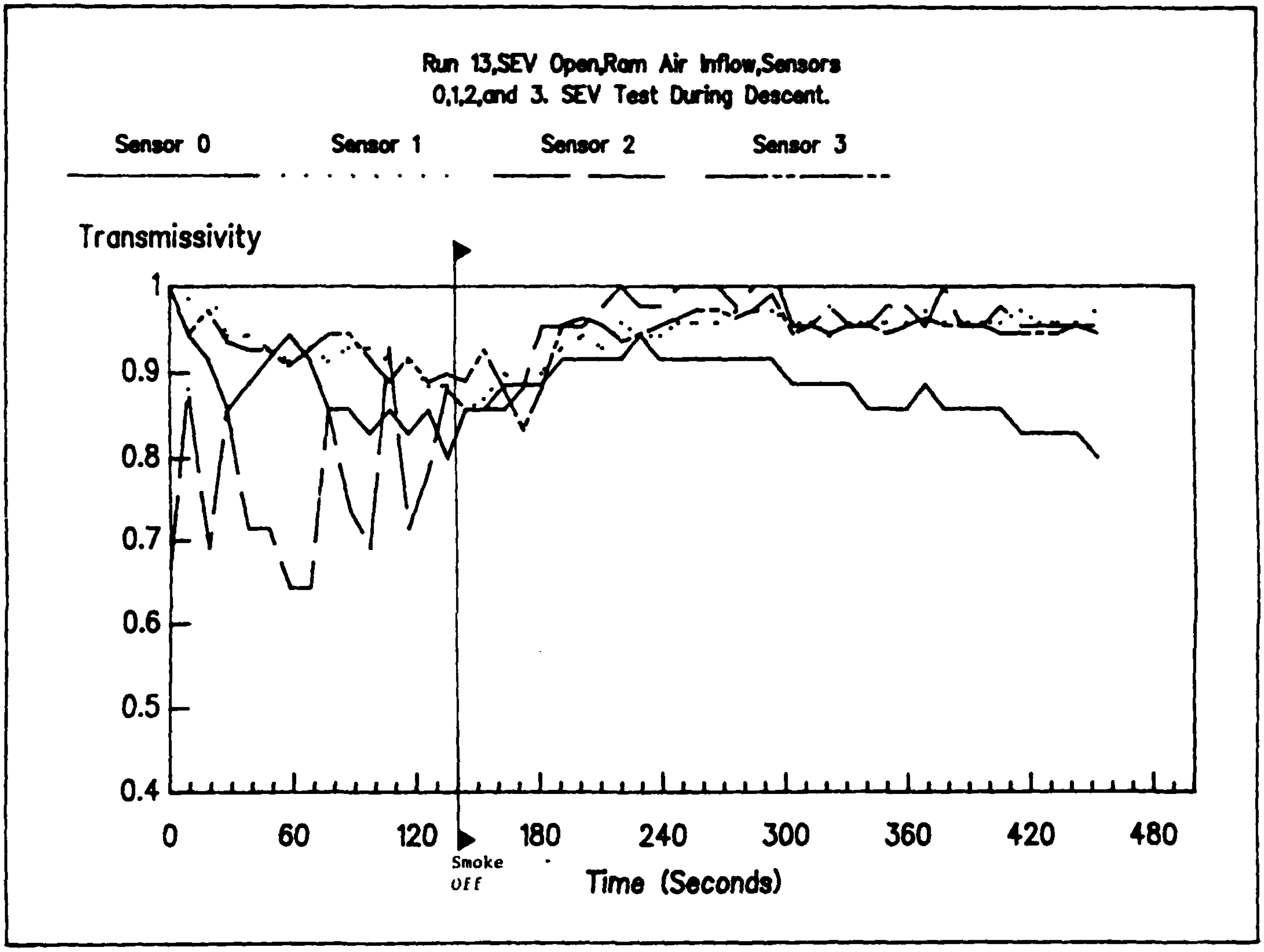

Run 13,SEV Open,Ram Air Inflow,Sensors
0,1,2,and 3. SEV Test During Descent.
Sensor 0
Sensor 1
Sensor 2
Sensor 3
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke
Off
Time (Seconds)

FIGURE A-13

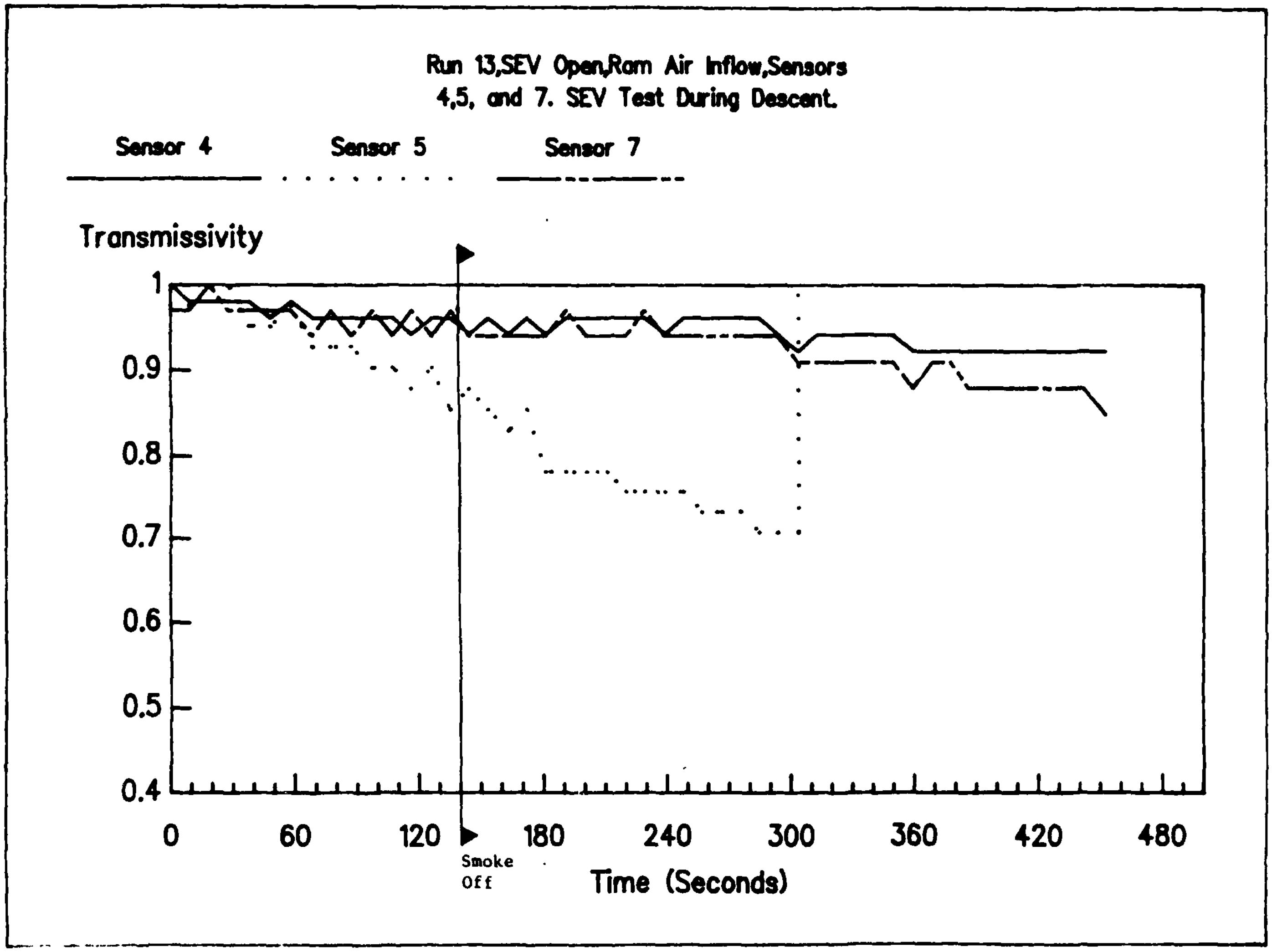

Run 13,SEV Open,Ram Air Inflow,Sensors
4,5, and 7. SEV Test During Descent.
Sensor 4
Sensor 5
Sensor 7
Transmissivity
1
0.9
0.8
0.7
0.6
0.5
0.4
0
60
120
180
240
300
360
420
480
Smoke
Off
Time (Seconds)

FIGURE A-14

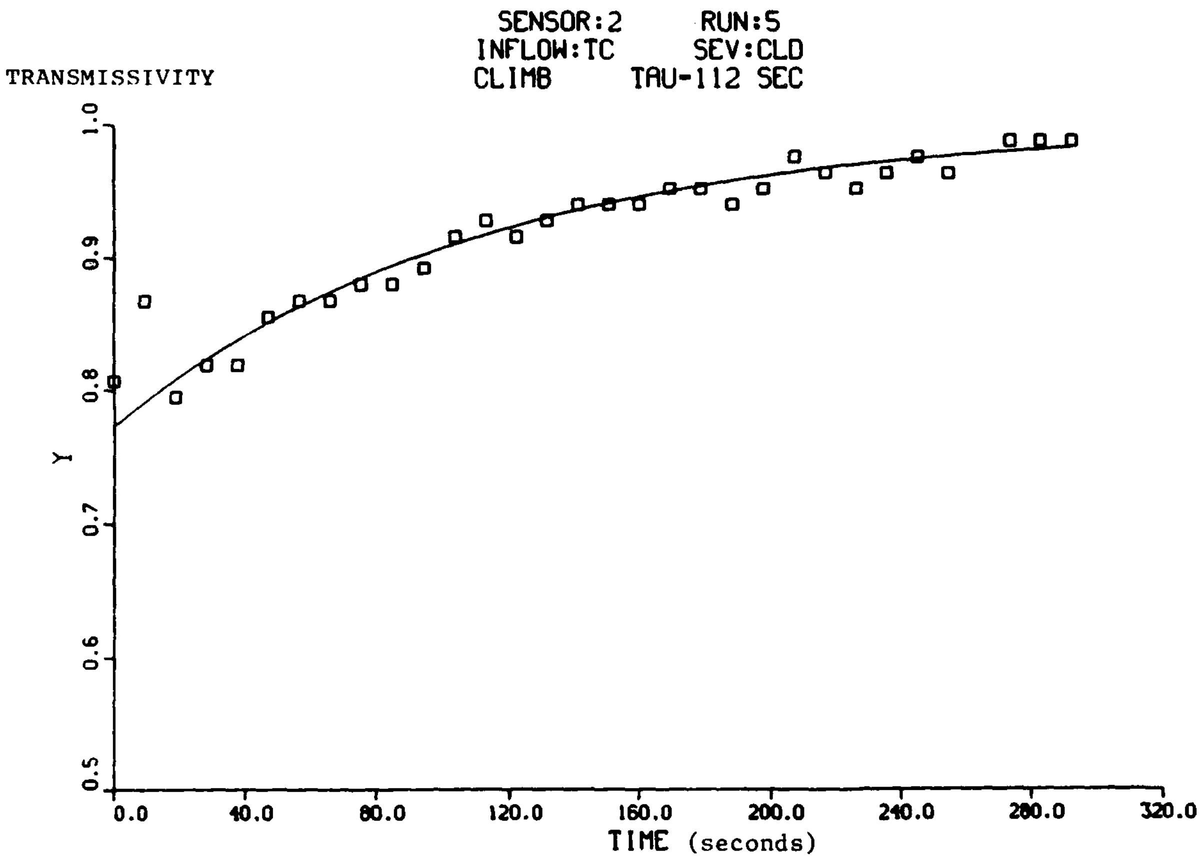

SENSOR:2 RUN:5
INFLOW:TC SEV:CLD
CLIMB TAU-112 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-1

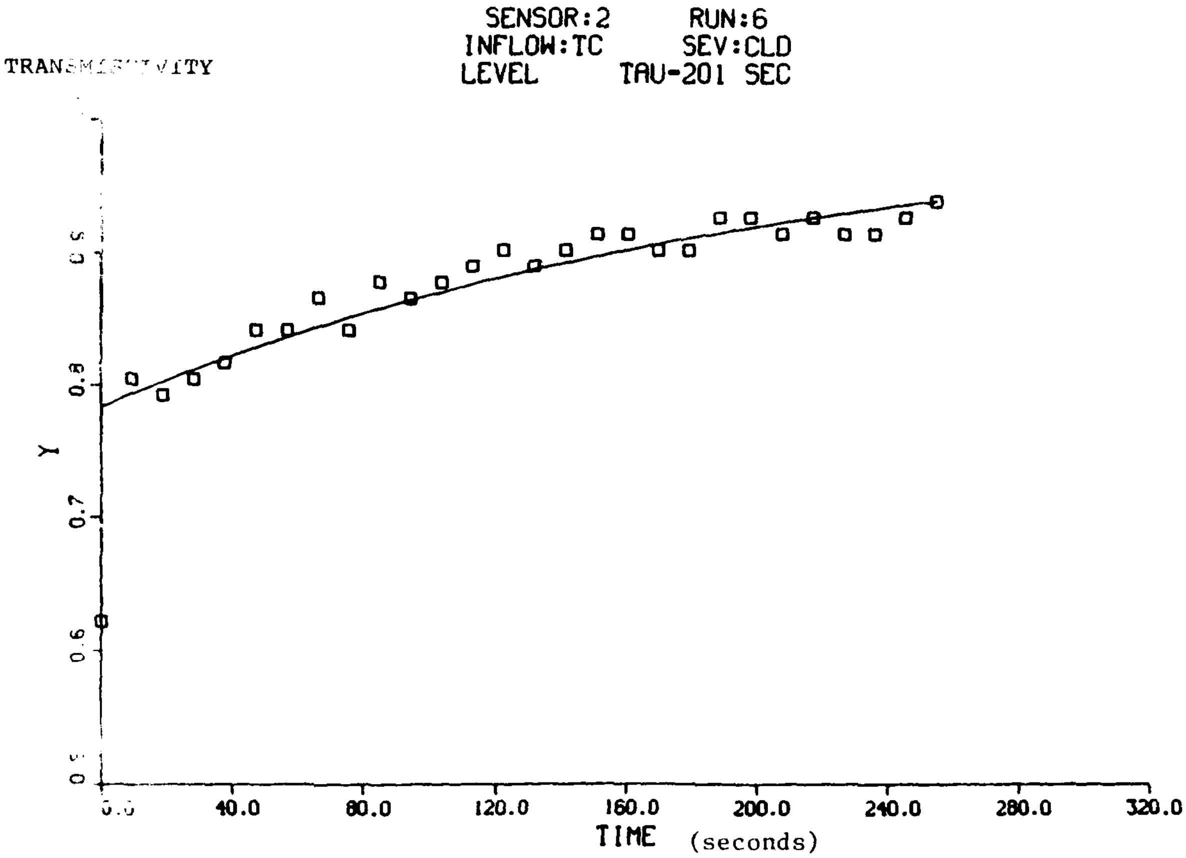

SENSOR:2 RUN:6
INFLOW:TC SEV:CLD
LEVEL TAU-201 SEC
Y
0.8
0.7
0.6
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-2

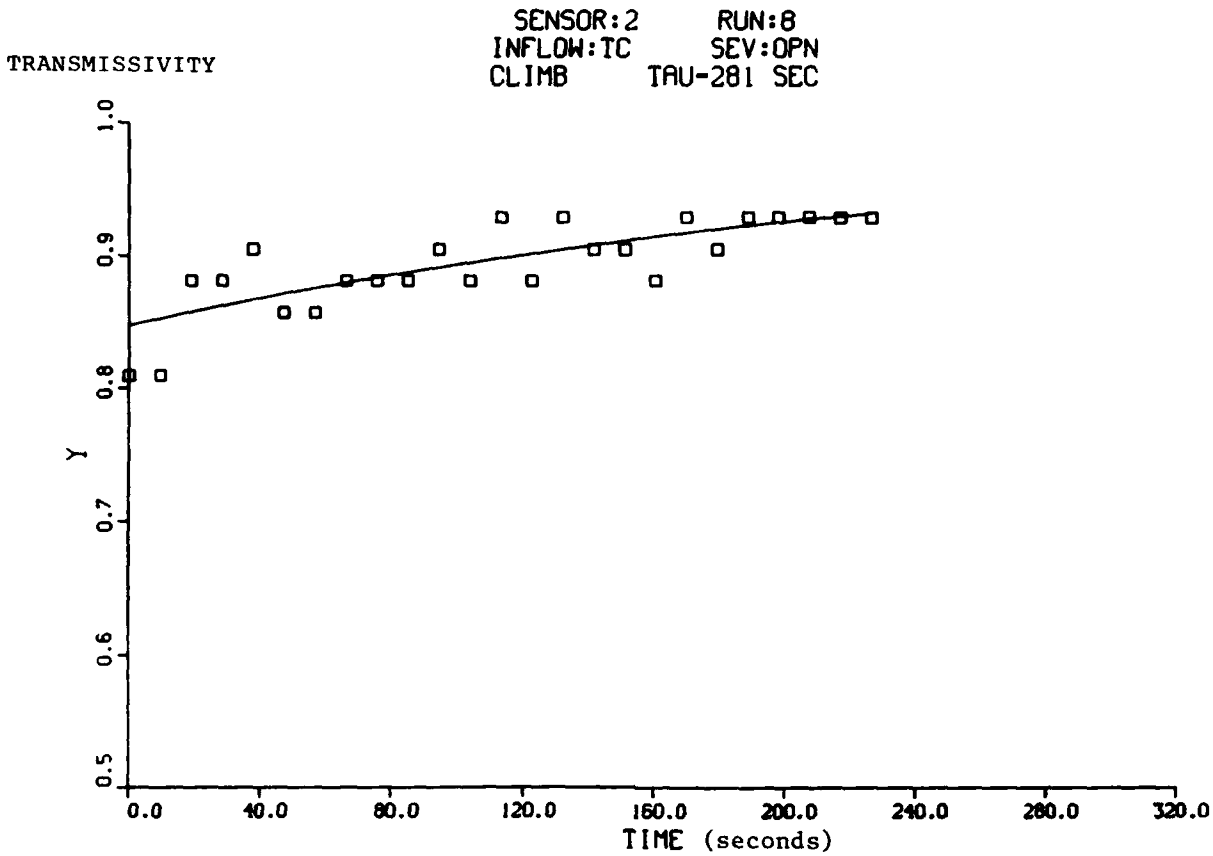
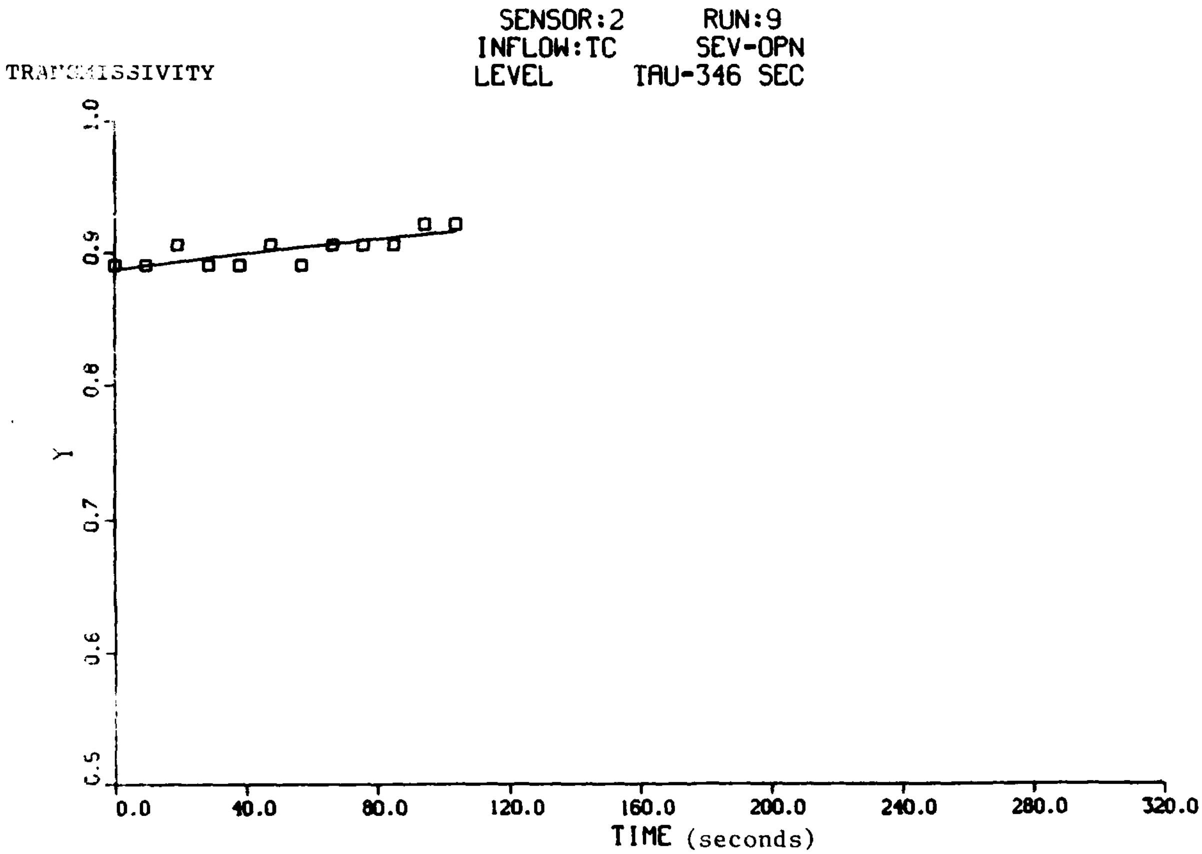
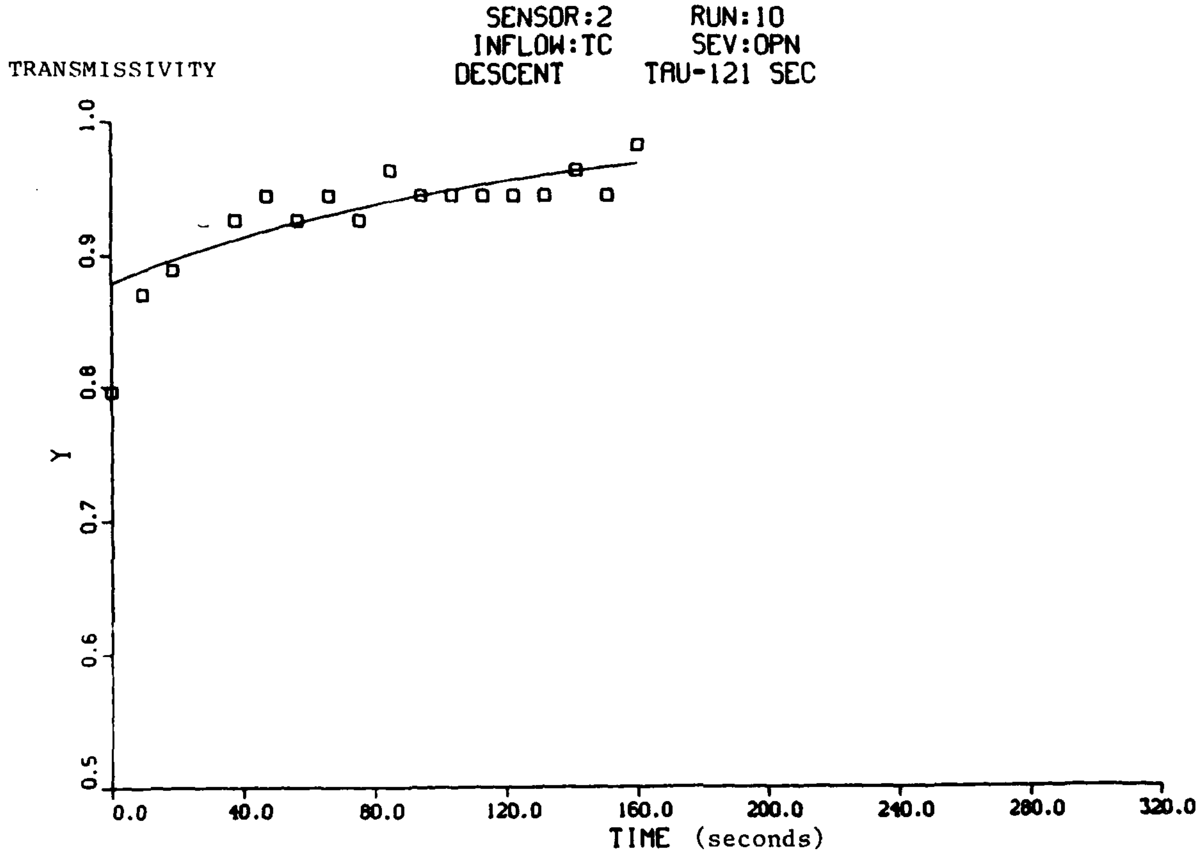

SENSOR:2 RUN:8
INFLOW:TC SEV:OPN
CLIMB TAU-281 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-3



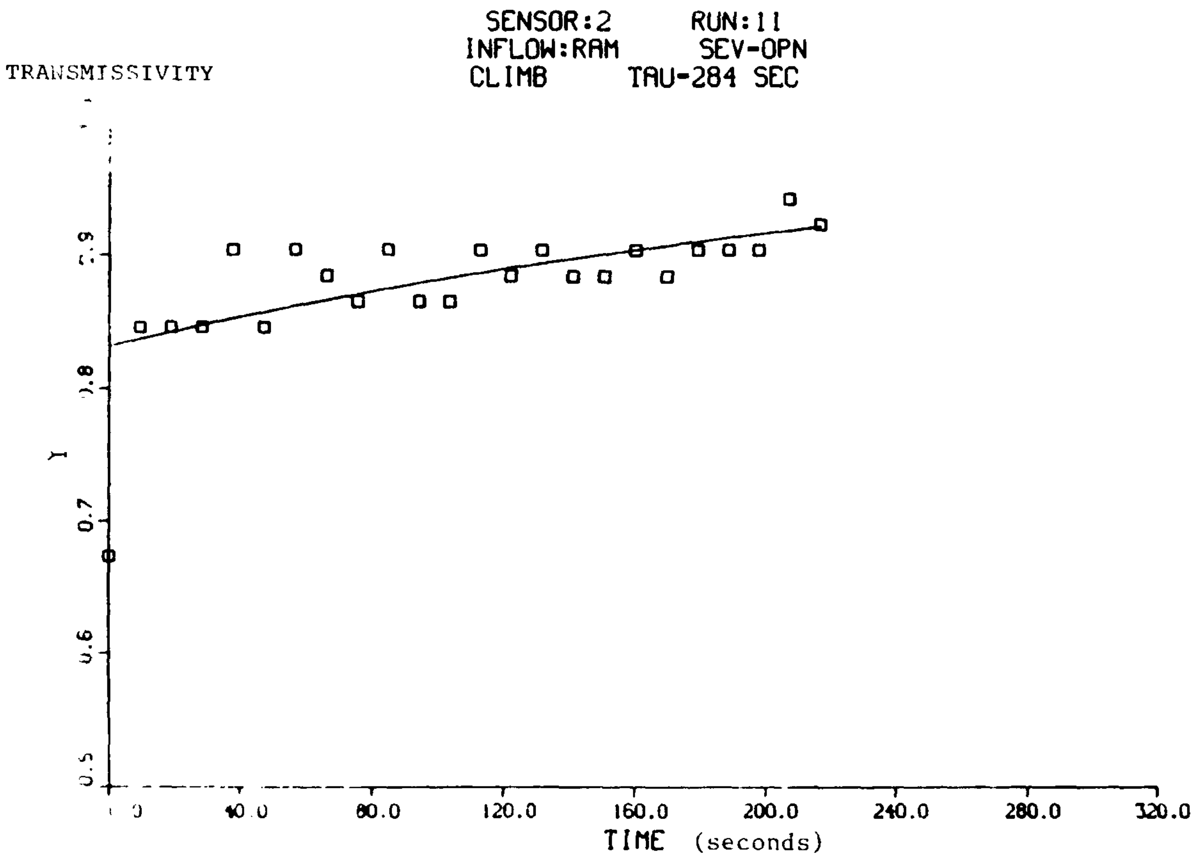
SENSOR:2 RUN:9
INFLOW:TC SEV-OPN
LEVEL TAU-346 SEC
TRANSMISSIVITY
1.0
0.9
0.8
Y
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-4



SENSOR:2 RUN:10
INFLOW:TC SEV:OPN
DESCENT TAU-121 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-5



SENSOR:2 RUN:11
INFLOW:RAM SEV-OPN
CLIMB TAU-284 SEC
TRANSMISSIVITY
0.9
0.8
0.7
0.6
0.5
Y
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-6

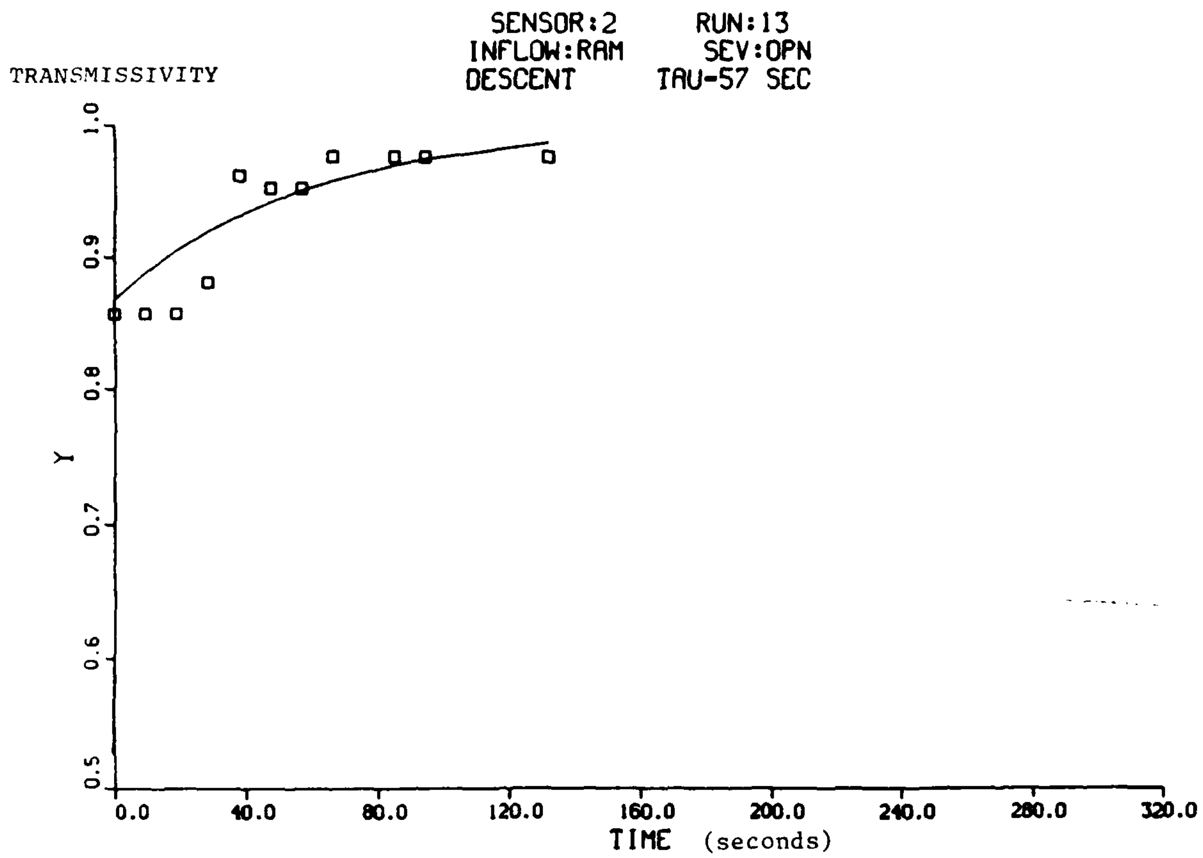

SENSOR:2 RUN:13
INFLOW:RAM SEV:OPN
DESCENT TAU-57 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-7

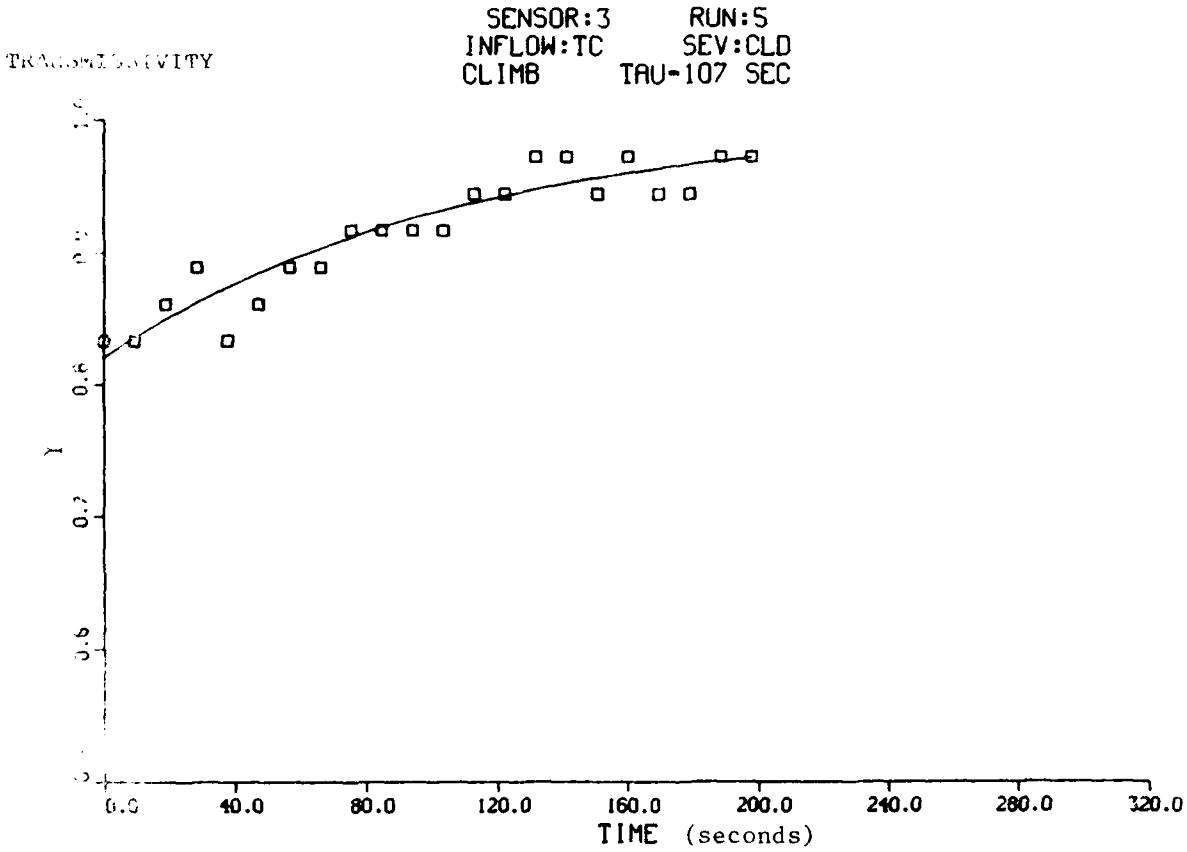

SENSOR:3 RUN:5
INFLOW:TC SEV:CLD
CLIMB TAU-107 SEC
TRANSMISSIVITY
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-8

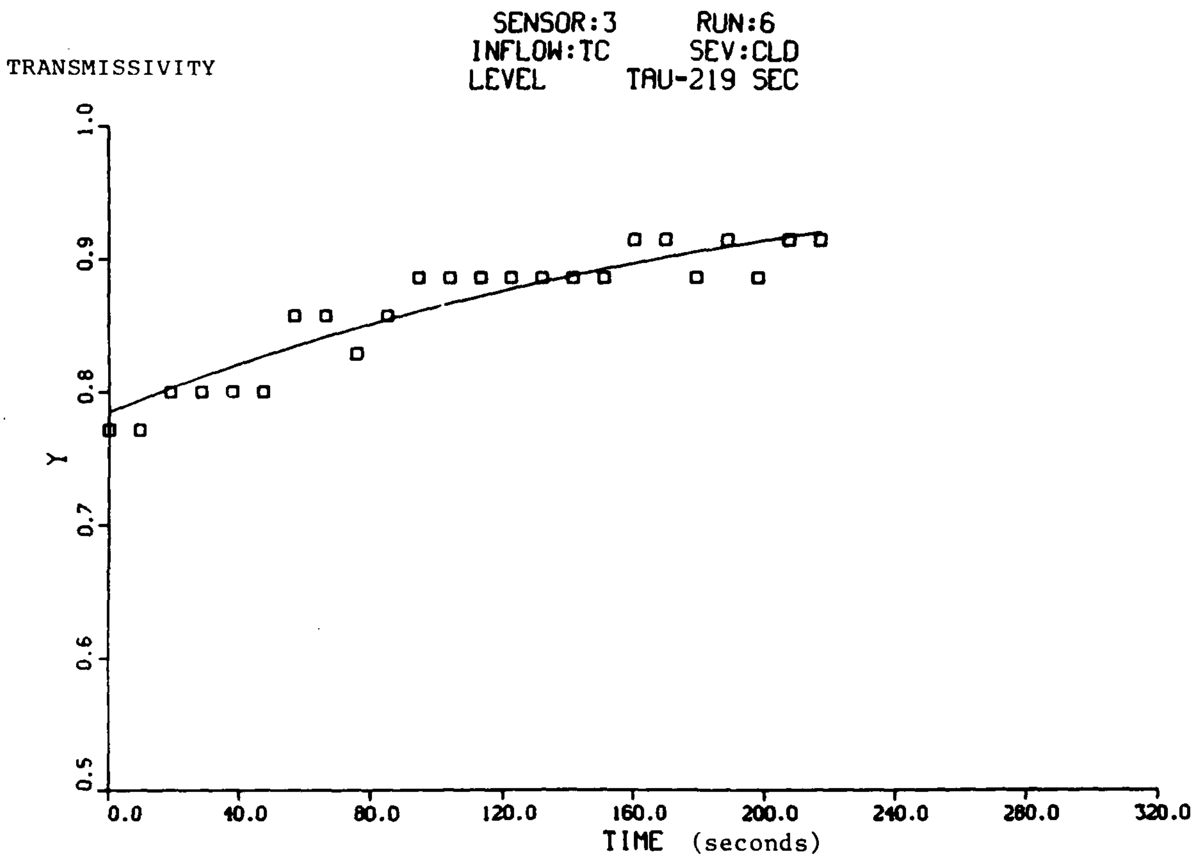

SENSOR:3 RUN:6
INFLOW:TC SEV:CLD
LEVEL TAU-219 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-9

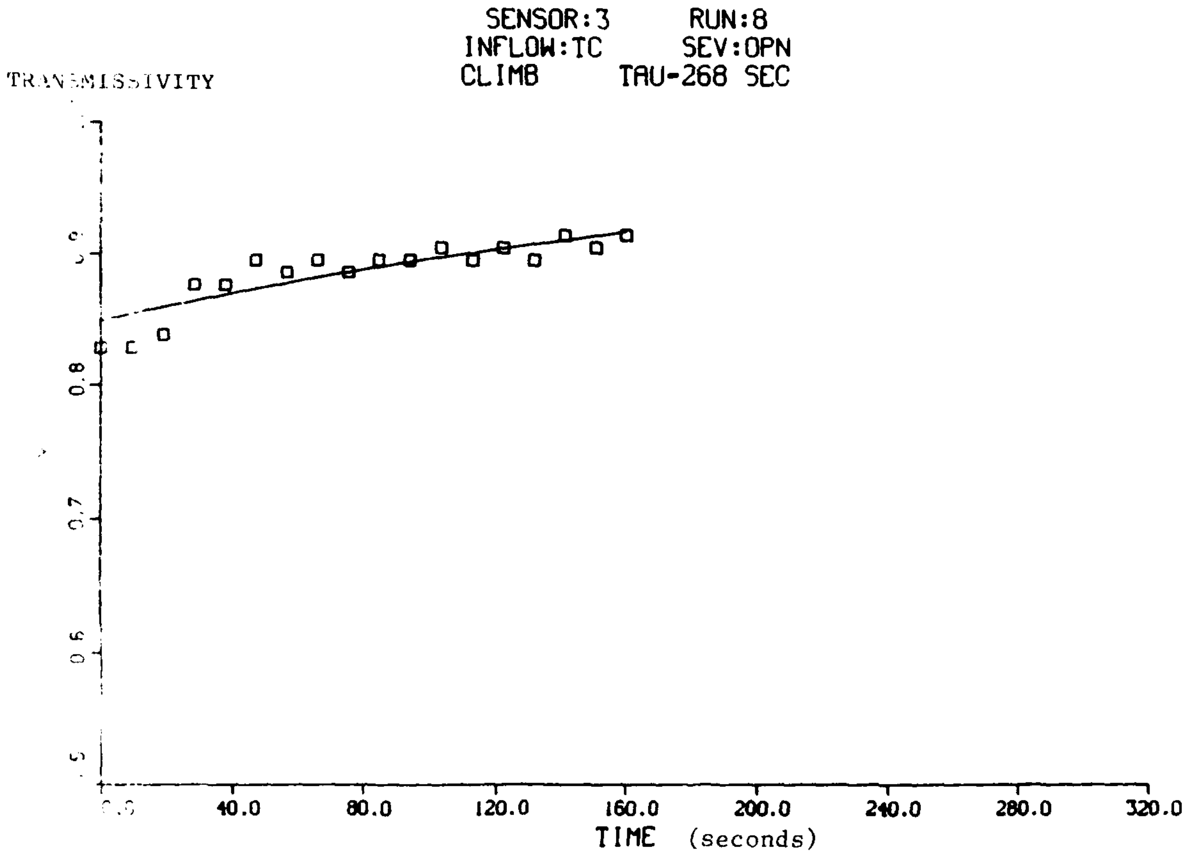

SENSOR:3 RUN:8
INFLOW:TC SEV:OPN
CLIMB TAU-268 SEC
TRANSMISSIVITY
0.8
0.7
0.6
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-10

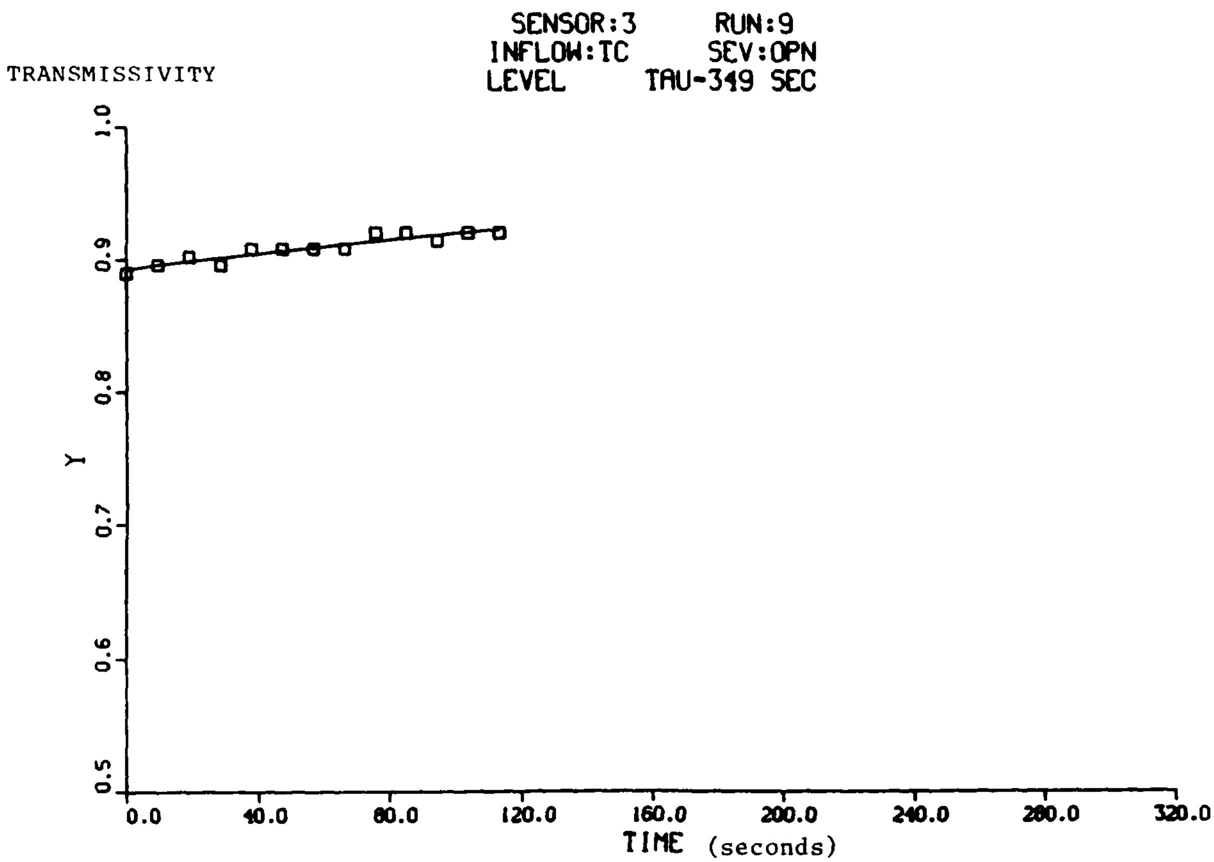

SENSOR:3 RUN:9
INFLOW:TC SEV:OPN
LEVEL TAU-349 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-11

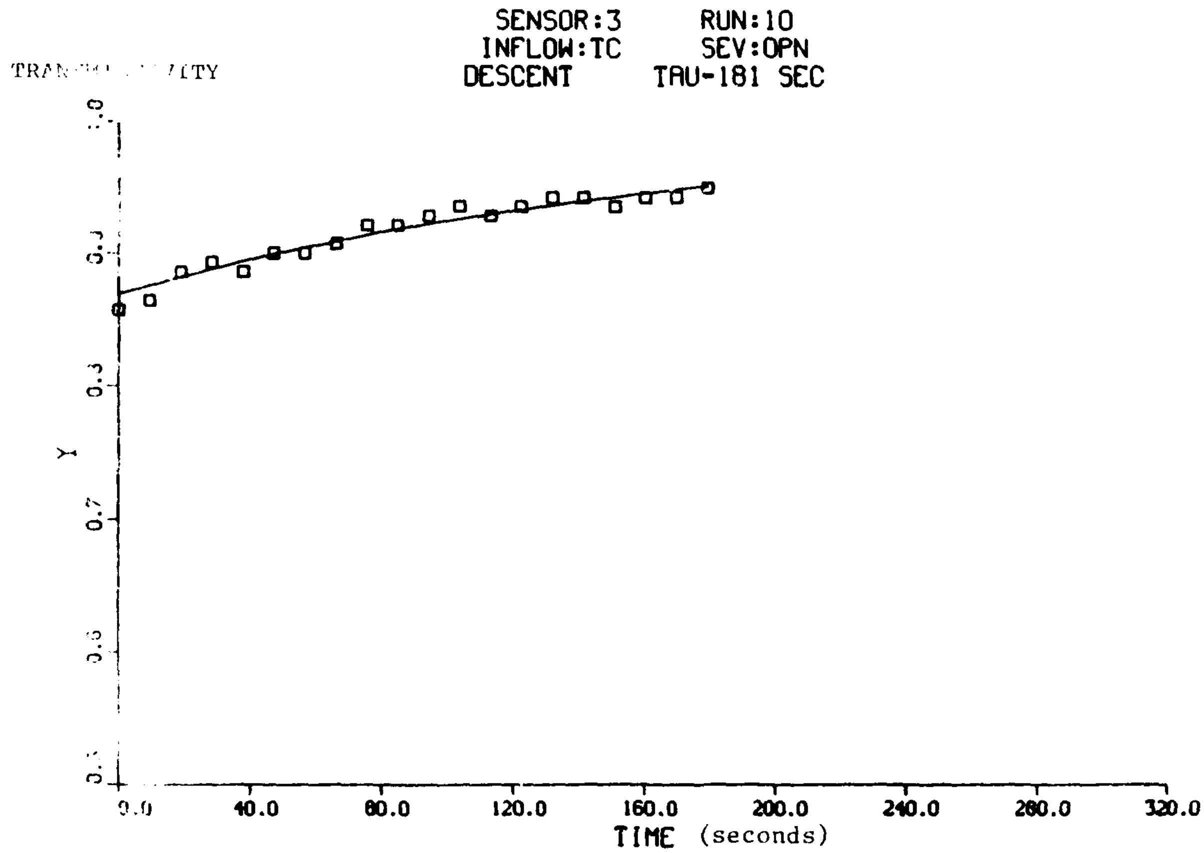
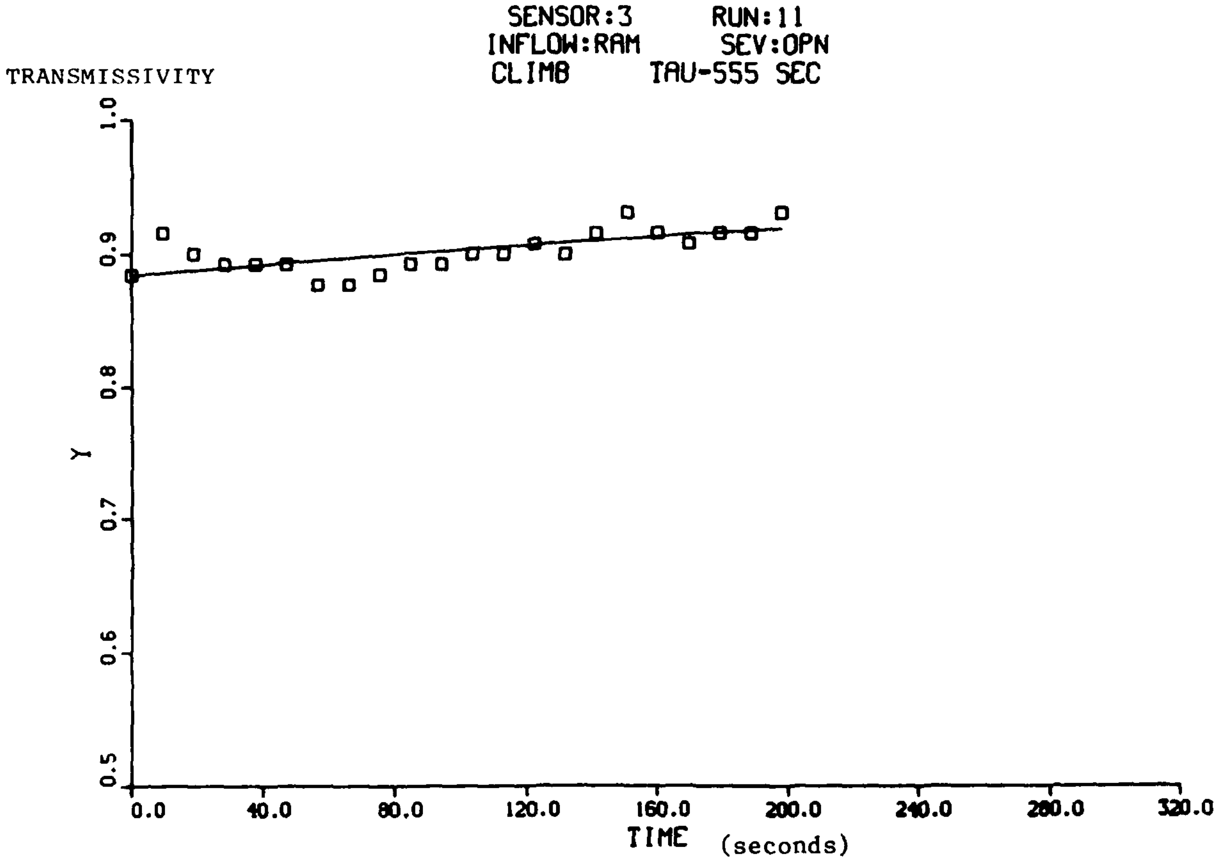

SENSOR:3 RUN:10
INFLOW:TC SEV:OPN
DESCENT TAU-181 SEC
Y
0.7
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-12



SENSOR:3 RUN:11
INFLOW:RAM SEV:OPN
CLIMB TAU-555 SEC
TRANSMISSIVITY
Y
1.0
0.9
0.8
0.7
0.6
0.5
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-13

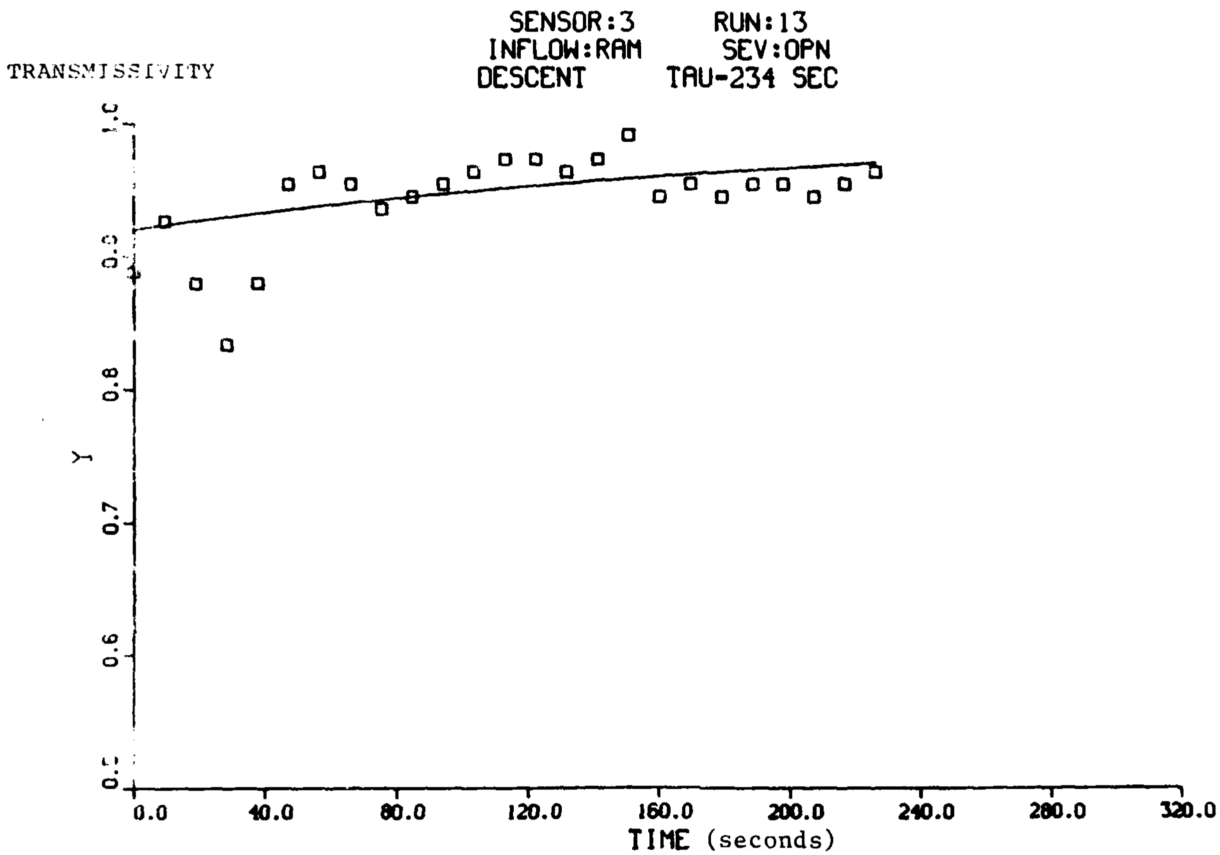

SENSOR:3 RUN:13
INFLOW:RAM SEV:OPN
DESCENT TAU-234 SEC
TRANSMISSIVITY
Y
0.6
0.7
0.8
0.0
40.0
80.0
120.0
160.0
200.0
240.0
280.0
320.0
TIME (seconds)

FIGURE B-14

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